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OF

MINERALOGY

WITH AN EXTENDED TREATISE ON

CRYSTALLOGRAPHY AND PHYSICAL MINERALOGY

BY

EDWARD SALISBURY DANA
Professor Emeritus of Physics and Curator of Mineralogy
Yale University

THIRD EDITION, REVISED AND ENLARGED

BY

WILLIAM E. FORD
Professor of Mineralogy, Sheffield Scientific School of
Yale University

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PREFACE TO THE THIRD EDITION

The first edition of this book appeared in 1877 and approximately twenty years later (1898) the second and revised edition was published. Now, again after more than twenty years, comes the third edition. The changes involved in the present edition are chiefly those of addition, the general character and form of the book having been retained unchanged. In the section on Crystallography the important change consists in the introduction of the methods employed in the use of the stereographic and gnomonic projections. A considerable portion of the section on the Optical Characters of Minerals has been rewritten in the endeavor to make this portion of the book simpler and more readily understood by the student. In the section on Descriptive Mineralogy all species described since the previous edition have been briefly mentioned in their proper places. Numerous other changes and corrections have, of course, been made in order to embody the results of mineral investigation during the last two decades. Only minor changes have been made in the order of classification of the mineral species. It was felt that as this book is so closely related to the System of Mineralogy it was unwise to attempt any revision of the chemical classification until a new edition of that work should appear. The description of the methods of Crystal Drawing given in Appendix A has been largely rewritten. A new table has been added to Appendix B in which the minerals have been grouped into lists according to their important basic elements. Throughout the book the endeavor has been to present in a clear and concise way all the information needed by the elementary and advanced student of the science.

The editor of this edition is indebted especially to the published and unpublished writings of the late Professor Samuel L. Penfield for much material and many figures that have been used in the sections of Crystallography and The Optical Character of Minerals. He also acknowledges the cordial support and constant assistance given him by Professor Edward S. Dana.

WILLIAM E. FORD

NEW HAVEN, CONN., Dec. 1, 1921.

489105

PREFACE TO THE SECOND EDITION

The remarkable advance in the Science of Mineralogy, during the years that have elapsed since this Text-Book was first issued in 1877, has made it necessary, in the preparation of a new edition, to rewrite the whole as well as to add much new matter and many new illustrations.

The work being designed chiefly to meet the wants of class or private instruction, this object has at once determined the choice of topics discussed, the order and fullness of treatment and the method of presentation.

In the chapter on Crystallography, the different types of crystal forms are described under the now accepted thirty-two groups classed according to their symmetry. The names given to these groups are based, so far as possible, upon the characteristic form of each, and are intended also to suggest the terms formerly applied in accordance with the principles of hemihedrism. The order adopted is that which alone seems suited to the demands of the elementary student, the special and mathematically simple groups of the isometric system being described first. Especial prominence is given to the "normal group" under the successive systems, that is, to the group which is relatively of most common occurrence and which shows the highest degree of symmetry. The methods of Miller are followed as regards the indices of the different forms and the mathematical calculations.

In the chapters on Physical and Chemical Mineralogy, the plan of the former edition is retained of presenting somewhat fully the elementary principles of the science upon which the mineral characters depend; this is particularly true in the department of Optics. The effort has been made to give the student the means of becoming practically familiar with all the modern methods of investigation now commonly applied. Especial attention is, therefore, given to the optical properties of crystals as revealed by the microscope. Further, frequent references are introduced to important papers on the different subjects discussed, in order to direct the student's attention to the original literature.

The Descriptive part of the volume is essentially an abridgment of the Sixth Edition of Dana's System of Mineralogy, prepared by the author (1892). To this work (and future Appendices) the student is, therefore, referred for fuller descriptions of the crystallographic and optical properties of species, for analyses, lists of localities, etc.; also for the authorities for data here quoted. In certain directions, however, the work has been expanded when the interests of the student have seemed to demand it; for example, in the statement of the characters of the various isomorphous groups. Attention is also called to the paragraph headed "**Diff.**," in the description of each common species, in which are given the distinguishing characters, particularly those which serve to separate it from other species with which it might be easily confounded.

The list of American localities of minerals, which appeared as an Appendix in the earlier edition, has been omitted, since in its present expanded form it requires more space than could well be given to it; further, its reproduction here is unnecessary since it is accessible to all interested not only in the System of Mineralogy but also in separate form. A full topical Index has been added, besides the usual Index of Species.

The obligations of the present volume to well-known works of other authors — particularly to those of Groth and Rosenbusch — are too obvious to require special mention. The author must, however, express his gratitude to his colleague, Prof. L. V. Pirsson, who has given him material aid in the part of the work dealing with the optical properties of minerals as examined under the microscope. He is also indebted to Prof. S. L. Penfield of New Haven and to Prof. H. A. Miers of Oxford, England, for various valuable suggestions.

EDWARD SALISBURY DANA

NEW HAVEN, CONN., Aug. 1, 1898.

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INTRODUCTION

1. The Science of Mineralogy treats of those inorganic species called *minerals*, which together in rock masses or in isolated form make up the material of the crust of the earth, and of other bodies in the universe so far as it is possible to study them in the form of meteorites.

2. **Definition of a Mineral.** — *A Mineral is a body produced by the processes of inorganic nature, having a definite chemical composition and, if formed under favorable conditions, a certain characteristic molecular structure which is exhibited in its crystalline form and other physical properties.*

This definition calls for some further explanation.

First of all, a mineral must be a *homogeneous* substance, even when minutely examined by the microscope; further, it must have a *definite chemical composition*, capable of being expressed by a chemical formula. Thus, much basalt appears to be homogeneous to the eye, but when examined under the microscope in thin sections it is seen to be made up of different substances, each having characters of its own. Again, obsidian, or volcanic glass, though it may be essentially homogeneous, has not a definite composition corresponding to a specific chemical formula, and is hence classed as a rock, not as a mineral species. Further, several substances, as tachylyte, hyalomelane, etc., which at one time passed as minerals, have been relegated to petrology, because it has been shown that they are only local forms of basalt, retaining an apparently homogeneous form due to rapid cooling.

Again, a mineral has in all cases a *definite molecular structure*, unless the conditions of formation have been such as to prevent this, which is rarely true. This molecular structure, as will be shown later, manifests itself in the physical characters and especially in the external crystalline form.

It is customary, as a matter of convenience, to limit the name mineral to those compounds which have been formed by the processes of nature alone, while compounds made in the laboratory or the smelting-furnace are at most called artificial minerals. Further, mineral substances which have been produced through the agency of organic life are not included among minerals, as the pearl of an oyster, the opal-silica (tabasheer) secreted by the bamboo, etc. Finally, mineral species are, as a rule, limited to *solid substances;* the only liquids included being metallic mercury and water. Petroleum, or mineral oil, is not properly a homogeneous substance, consisting rather of several hydrocarbon compounds; it is hence not a mineral species.

It is obvious from the above that minerals, in the somewhat restricted sense usually adopted, constitute only a part of what is often called the Mineral Kingdom.

3. **Scope of Mineralogy.** — In the following pages, the general subject of mineralogy is treated under the following heads:

(1) *Crystallography.* — This comprises a discussion of crystals in general and especially of the crystalline forms of mineral species.

(2) *Physical Mineralogy.* — This includes a discussion of the physical characters of minerals, that is, those depending upon cohesion and elasticity, density, light, heat, electricity, and so on.

(3) *Chemical Mineralogy.* — Under this head are presented briefly the general principles of chemistry as applied to mineral species; their characters as chemical compounds are described, also the methods of investigating them from the chemical side by the blowpipe and other means.

(4) *Descriptive Mineralogy.* — This includes the classification of minerals and the description of each species with its varieties, especially in its relations to closely allied species, as regards crystalline form, physical and chemical characters, occurrence in nature, and other points.

4. Literature. — Reference is made to the Introduction to the Sixth Edition of Dana's System of Mineralogy, pp. xlv–lxi, for an extended list of independent works on Mineralogy up to 1892 and to its Appendices I, II and III for works published up to 1915; the names are also given of the many scientific periodicals which contain original memoirs on mineralogical subjects. For the convenience of the student the titles of a few works, mostly of a general character, are given here. Further references to the literature of Mineralogy are introduced through the first half of this work, particularly at the end of the sections dealing with special subjects.

Crystallography and Physical Mineralogy

EARLY WORKS* include those of Romé de l'Isle, 1772; Haüy, 1822; Neumann, Krystallonomie, 1823, and Krystallographie, 1825; Kupffer, 1825; Grassmann, Krystallonomie, 1829; Naumann, 1829 and later; Quenstedt, 1846 (also 1873); Miller, 1839 and 1863; Grailich, 1856; Kopp, 1862; von Lang, 1866; Bravais, Études Crist., Paris, 1866 (1849); Schrauf, 1866–68; Rose-Sadebeck, 1873.

RECENT WORKS include the following:

Bayley. Elementary Crystallography, 1910.

Beale. Introduction to Crystallography, 1915.

Beckenkamp. Statische und kinetische Kristalltheorien, 1913–.

Bruhns. Elemente der Krystallographie, 1902.

Goldschmidt. Index der Krystallformen der Mineralien; 3 vols., 1886–91. Also Anwendung der Linearprojection zum Berechnen der Krystalle, 1887. Atlas der Krystallformen, 1913–.

Gossner. Kristallberechnung und Kristallzeichnung, 1914.

Groth. Physikalische Krystallographie und Einleitung in die krystallographische Kenntniss der wichtigeren Substanzen, 1905.

Klein. Einleitung in die Krystallberechnung, 1876

Lewis. Crystallography, 1899.

Liebisch. Geometrische Krystallographie, 1881. Physikalische Krystallographie, 1891.

Mallard. Traité de Cristallographie géométrique et physique; vol. 1, 1879; vol. 2, 1884.

Moses. Characters of Crystals, 1899.

Reeks. Hints for Crystal Drawing, 1908.

Sadebeck. Angewandte Krystallographie (Rose's Krystallographie, II. Band), 1876.

Sohncke. Entwickelung einer Theorie der Krystallstruktur, 1879.

Sommerfeldt. Physikalische Kristallographie, 1907; Die Kristallgruppe, 1911.

Story-Maskelyne. Crystallography: the Morphology of Crystals, 1895.

Tutton. Crystalline Structure and Chemical Constitution, 1910; Crystallography and Practical Crystal Measurement, 1911.

Viola. Grundzüge der Kristallographie, 1904.

Walker. Crystallography, 1914.

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* The full titles of many of these are given in pp. li–lxi of Dana's System of Mineralogy, 1892.

Wallerant. Cristallographie, 1909.

Websky. Anwendung der Linearprojection zum Berechnen der Krystalle (Rose's Krystallographie III. Band), 1887.

Williams. Elements of Crystallography, 1890.

Wülfing. Die 32 krystallographischen Symmetrieklassen und ihre einfachen Formen, 1914.

In Physical Mineralogy the most important general works are those of Schrauf (1868), Mallard (1884), Liebisch (1891), mentioned in the above list; also Rosenbusch, Mikr. Physiographie, etc. (1892). Important later works include the following.

Davy-Farnham. Microscopic Examination of the Ore Minerals, 1920.

Duparc and Pearce. Traité de Technique Minéralogique et Pétrographique, 1907.

Groth. Physikalische Krystallographie, 1905.

Groth-Jackson. Optical Properties of Crystals, 1910.

Johannsen. Determination of Rock-Forming Minerals, 1908. Manual of Petrographic Methods, 1914.

Murdoch. Microscopical Determination of the Opaque Minerals, 1916.

Nikitin, translated into French by **Duparc and de Dervies.** La Methode Universelle de Fedoroff, 1914.

Winchell. Elements of Optical Mineralogy, 1909.

Wright. The Methods of Petrographic-Microscopic Research, 1911.

General Mineralogy

Of the many works, a knowledge of which is needed by one who wishes a full acquaintance with the historical development of Mineralogy, the following are particularly important. Very early works include those of Theophrastus, Pliny, Linnæus, Wallerius, Cronstedt, Werner, Bergmann, Klaproth.

Within the nineteenth century: Haüy's Treatise, 1801, 1822; Jameson, 1816, 1820; Werner's Letztes Mineral-System, 1817; Cleaveland's Mineralogy, 1816, 1822; Leonhard's Handbuch, 1821, 1826; Mohs's Min., 1822; Haidinger's translation of Mohs, 1824; Breithaupt's Charakteristik, 1820, 1823, 1832; Beudant's Treatise, 1824, 1832; Phillips's Min., 1823, 1837; Shepard's Min., 1832–35, and later editions; von Kobell's Grundzüge, 1838; Mohs's Min., 1839; Breithaupt's Min., 1836–1847; Haidinger's Handbuch, 1845; Naumann's Min., 1846 and later; Hausmann's Handbuch, 1847; Dufrénoy's Min., 1844–1847 (also 1856–1859); Brooke & Miller, 1852; J. D. Dana's System of 1837, 1844, 1850, 1854, 1868.

More Recent Works are the following:

Bauer. Lehrbuch der Mineralogie, 1904.

Bauerman. Text-Book of Descriptive Mineralogy, 1884.

Baumhauer. Das Reich der Krystalle, 1889.

Bayley. Descriptive Mineralogy, 1917.

Blum. Lehrbuch der Mineralogie, 4th ed., 1873–1874.

Brauns. Das Mineralreich, 1903. English, translation by **Spencer,** 1912.

Clarke. The Data of Geochemistry, 1916.

Dana, E. S. Dana's System of Mineralogy, 6th ed., New York, 1892. Appendix I, 1899; II, 1909; III, 1915. Also (elementary) Minerals and How to study them, New York, 1895.

Dana-Ford. Manual of Mineralogy, 1912.

Des Cloizeaux. Manuel de Minéralogie; vol. 1, 1862; vol. 2, 1er Fasc., 1874; 2me. 1893.

Groth. Tabellarische Uebersicht der Mineralien, 1898.

Hintze. Handbuch der Mineralogie, 1889–1915.

Iddings. Rock Minerals, 1906.

Kraus. Descriptive Mineralogy, 1911.

Lacroix. Minéralogie de la France et de ses Colonies, 5 vols., 1893–1913.

Miers. Mineralogy, 1902.

Moses and Parsons. Mineralogy, Crystallography and Blowpipe Analysis, 1916.

Merrill. The Non-metallic Minerals, 1904.

Phillips. Mineralogy, 1912.

Rogers. Study of Minerals, 1912.

Schrauf. Atlas der Krystall-Formen des Mineralreiches, 4to, vol. 1, A–C, 1865–1877.

Tschermak. Lehrbuch der Mineralogie, 1884; 5th ed., 1897.

Weisbach. Synopsis Mineralogica, systematische Uebersicht des Mineralreiches, 1875.

Zirkel. 13th edition of Naumann's Mineralogy, Leipzig, 1897.

Wülfing. Die Meteoriten in Sammlungen, etc., 1897 (earlier works on related subjects, see Dana's System, p. 32).

For a catalogue of localities of minerals in the United States and Canada see the volume (51 pp.) reprinted from Dana's System, 6th ed. See also the volumes on the Mineral Resources of the United States published (since 1882) under the auspices of the U. S. Geological Survey.

Chemical and Determinative Mineralogy

Bischoff. Lehrbuch der chemischen und physikalischen Geologie, 1847–54; 2d ed., 1863–66. (Also an English edition.)

Blum. Die Pseudomorphosen des Mineralreichs, 1843. With 4 Nachträge, 1847–1879.

Brush-Penfield. Manual of Determinative Mineralogy, with an Introduction on Blowpipe Analysis, 1896.

Doelter. Allgemeine chemische Mineralogie, Leipzig, 1890. Handbuch der Mineralchemie, 1912–.

Duparc and **Monnier.** Traité de Technique Minéralogique et Pétrographique, 1913.

Eakle. Mineral Tables for the Determination of Minerals by their Physical Properties, 1904.

Endlich. Manual of Qualitative Blowpipe Analysis, New York, 1892.

Kobell, F. von. Tafeln zur Bestimmung der Mineralien mitteist einfacher chemischer Versuche auf trockenem und nassem Wege, 11te Auflage, 1878.

Kraus and **Hunt.** Tables for the Determination of Minerals, 1911.

Lewis. Determinative Mineralogy, 1915.

Rammelsberg. Handbuch der krystallographisch-physikalischen Chemie, Leipzig, 1881–82. Handbuch der Mineralchemie, 2d ed., 1875. Ergänzungsheft, 1, 1886; 2, 1895.

Roth. Allgemeine und chemische Geologie; vol. 1, Bildung u. Umbildung der Mineralien, etc., 1879; 2, Petrographie, 1887–1890.

Websky. Die Mineral Species nach den für das specifische Gewicht derselben angenommenen und gefundenen Werthen, Breslau, 1868.

Weisbach. Tabellen zur Bestimmung der Mineralien nach äusseren Kennzeichen, 3te Auflage, 1886. Also founded on Weisbach's work, **Frazer's** Tables for the determination of minerals, 4th ed., 1897.

Artificial Formation of Minerals

Dittler. Mineralsynthetisches Praktikum, 1915.

Gurlt. Uebersicht der pyrogeneten künstlichen Mineralien, namentlich der krystallisirten Hüttenerzeugnisse, 1857.

Fuchs. Die künstlich dargestellten Mineralien, 1872.

Daubrée. Études synthetique de Géologie expérimentale, Paris, 1879.

Fouqué and **M. Lévy.** Synthèse des Minéraux et des Roches, 1882.

Bourgeois. Réproduction artificielle des Minéraux, 1884.

Meunier. Les méthodes de synthèse en Minéralogie.

Vogt. Die Silikatschmelzlözungen, 1903–1904.

Mineralogical Journals

The following Journals are largely devoted to original papers on Mineralogy:

Amer. Min. The American Mineralogist, 1916.

Bull. Soc. Min. Bulletin de la Société Française de Minéralogie, 1878–.

Centralbl. Min. Centralblatt für Mineralogie, Geologie und Palæontologie, 1900–.

Fortschr. Min. Fortschritte der Mineralogie, Kristallographie und Petrographie, 1911–.

Jb. Min. Neues Jahrbuch für Mineralogie, Geologie und Palæontologie, etc., from 1833.

Min. Mag. The Mineralogical Magazine and Journal of the Mineralogical Society of Gt. Britain, 1876–.

Min. Mitth. Mineralogische und petrographische Mittheilungen, 1878–; Earlier, from 1871, Mineralogische Mittheilungen gesammelt von G. Tschermak.

Riv. Min. Rivista di Mineralogia e Crystallografia, 1887–.

Zs. Kr. Zeitschrift für Krystallographie und Mineralogie. 1877–.

ABBREVIATIONS

Ax. pl.	Plane of the optic axes.
Bx, Bx_a.	Acute bisectrix (p. 277).
Bx_o.	Obtuse bisectrix (p. 277).
B.B.	Before the Blowpipe (p. 330).
Comp.	Composition.
Diff.	Differences, or distinctive characters.
G.	Specific Gravity.
H.	Hardness.
Obs.	Observations on occurrence, etc.
O.F.	Oxidizing Flame (p. 331).
Pyr.	Pyrognostics or blowpipe and allied characters.
R.F.	Reducing Flame (p. 331).
Var.	Varieties.

The sign $\wedge$ is used to indicate the angle between two faces of a crystal, as *am* $(100 \wedge 110) = 44° 30'$.

PART I. CRYSTALLOGRAPHY

GENERAL MORPHOLOGICAL RELATIONS OF CRYSTALS

5. Crystallography. — The subject of Crystallography includes the description of the characters of crystals in general; of the various forms of crystals and their division into classes and systems; of the methods of studying crystals, including the determination of the mathematical relations of their faces, and the measurement of the angles between them; finally, a description of compound or twin crystals, of irregularities in crystals, of crystalline aggregates, and of pseudomorphous crystals.

6. Definition of a Crystal.— *A crystal* * *is the regular polyhedral form, bounded by smooth surfaces, which is assumed by a chemical compound, under the action of its intermolecular forces, when passing, under suitable conditions, from the state of a liquid or gas to that of a solid.*

As expressed in the foregoing definition, a crystal is characterized, first, by its definite internal molecular structure, and, second, by its external form. A crystal is the *normal* form of a mineral species, as of all solid chemical compounds; but the conditions suitable for the formation of a crystal of ideal perfection in symmetry of form and smoothness of surface are never fully realized. Further, many species usually occur not in distinct crystals, but in massive form, and in some exceptional cases the definite molecular structure is absent.

7. Molecular Structure in General.— By definite molecular structure is meant the special arrangement which the physical units, called *molecules*,† assume under the action of the forces exerted between them during the formation of the solid. Some remarks are given in a later article (p. 22 *et seq.*) in regard to the kinds of molecular arrangement theoretically possible, and their relation to the symmetry of the different systems and classes of crystals.

The definite molecular structure is the essential character of a crystal, and the external form is only one of the ways, although the most important, in which this structure is manifested. Thus it is found that all similar directions in a crystal, or a fragment of a crystal, have like physical characters,‡ as of elasticity, cohesion, action on light, etc. This is clearly shown by the cleavage, or natural tendency to fracture in certain directions, yielding more or less smooth surfaces; as the cubic cleavage of galena, or the rhombohedral cleavage of calcite. It is evident, therefore, that a small crystal differs from a large one only in size, and that a fragment of a crystal is itself essentially a crystal in all its physical relations, though showing no crystalline faces.

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* In its original signification the term *crystal* was applied only to crystals of quartz, which the ancient philosophers believed to be *water* congealed by intense cold. Hence the term, from κρύσταλλος, *ice*.

† Recent studies, particularly those made by the use of the X-ray, would indicate that the unit of crystalline structure is the atom rather than the molecule. The grouping of the atoms to form a molecule is extended in the analogous grouping of the molecules to form a crystal.

‡ This subject is further elucidated in the chapter devoted to Physical Mineralogy, where it is also shown that, with respect to many, but not all, of the physical characters, the converse of this proposition is true, *viz.*, that unlike directions in a crystal have in general unlike properties.

Further, the external form without the corresponding molecular structure does not make a crystal of a solid. A model of glass or wood is obviously not a crystal, though having its external form, because there is no relation between form and structure. Also, an octahedron of malachite, having the form of the crystal of cuprite from which it has been derived by chemical alteration, is not a crystal of malachite, but what is known as a pseudomorph (see Art. **478**) of malachite after cuprite.

On the other hand, if the natural external faces are wanting, the solid is not called a crystal. A cleavage octahedron of fluorite and a cleavage rhombohedron of calcite are not properly crystals, because the surfaces have been yielded by fracture and not by the natural molecular growth of the crystal.

8. Crystalline and Amorphous. — When a mineral shows no external crystalline form, it is said to be *massive*. It may, however, have a definite molecular structure, and then it is said to be *crystalline*. If this structure, as shown by the cleavage, or by optical means, is the same in all parallel directions through the mass, it is described as a single individual. If it varies from grain to grain, or fiber to fiber, it is said to be a *crystalline aggregate*,* since it is in fact made up of a multitude of individuals.

Thus in a granular mass of galena or calcite, it may be possible to separate the fragments from one another, each with its characteristic cubic, or rhombohedral, cleavage. Even if the individuals are so small that they cannot be separated, yet the cleavage, and hence the crystalline structure, may be evident from the spangling of a freshly broken surface, as with fine-grained statuary marble. Or, again, this aggregate structure may be so fine that the crystalline structure can only be resolved by optical methods with the aid of the microscope. In all these cases, the structure is said to be *crystalline*.

If optical means show a more or less distinct crystalline structure, which, however, cannot be resolved into individuals, the mass is said to be *cryptocrystalline;* this is true of some massive varieties of quartz.

If the definite molecular structure is entirely wanting, and all directions in the mass are sensibly the same, the substance is said to be *amorphous*. This is true of a piece of glass, and nearly so of opal. The amorphous state is rare among minerals.

A piece of feldspar which has been fused and cooled suddenly may be in the glass-like amorphous condition as regards absence of definite molecular structure. But even in such cases there is a tendency to go over into the crystalline condition by molecular rearrangement. A transparent amorphous mass of arsenic trioxide (As_2O_3), formed by fusion, becomes opaque and crystalline after a time. Similarly the steel beams of a railroad bridge may gradually become crystalline and thus lose some of their original strength because of the molecular rearrangement made possible by the vibrations caused by the frequent jar of passing trains. The microscopic study of rocks reveals many cases in which an analogous change in molecular structure has taken place in a solid mass, as caused, for example, by great pressure.

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* The consideration of the various forms of crystalline aggregates is postponed to the end of the present chapter.

9. External Form. — A crystal is bounded by smooth plane surfaces, called faces or planes,* showing in their arrangement a certain characteristic symmetry, and related to each other by definite mathematical laws.

Thus, without inquiring, at the moment, into the exact meaning of the term symmetry as applied to crystals, and the kinds of symmetry possible, which will be explained in detail later, it is apparent that the accompanying figures, 1–3, show the external form spoken of. They represent, therefore, certain definite types.

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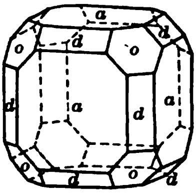

Galena

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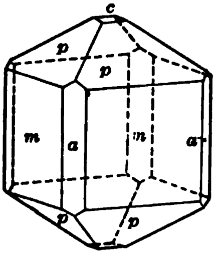
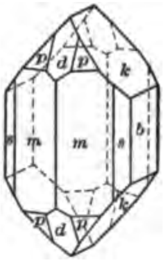


Vesuvianite

3



Chrysolite

10. Variation of Form and Surface. — Actual crystals deviate, within certain limits, from the ideal forms.

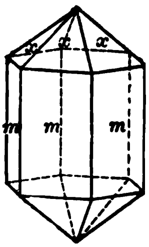
First, there may be variation in the size of like faces, thus producing what are defined later as *distorted forms*. In the second place, the faces are rarely absolutely smooth and brilliant; commonly they lack perfect polish, and they may even be rough or more or less covered with fine parallel lines (called striations), or show minute elevations, depressions or other peculiarities. Both the above subjects are discussed in detail in another place.

It may be noted in passing that the characters of natural faces, just alluded to, in general make it easy to distinguish between them and a face artificially ground, on the one hand, like the facet of a cut gem; or, on the other hand, the splintery uneven surface commonly yielded by cleavage.

11. Constancy of the Interfacial Angles in the Same Species. — The angles of inclination between like faces on the crystals of any species are essentially constant, wherever they are found, and whether products of nature or of the laboratory. These angles, therefore, form one of the important distinguishing characters of a species.

Thus, in Fig. 4, of apatite, the angle between the adjacent faces x and m (130° 18′) is the same for any two like faces, similarly situated with reference to each other. Further, this angle is constant for the species no matter what the size of the crystal may be or from what locality it may come. Moreover, the angles between all the faces on crystals of the same species (cf. Figs. 5–8 of zircon below) are more or less closely connected together by certain definite mathematical laws.

4



Apatite

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* This latter word is usually limited to cases where the direction, rather than the definite surface itself, is designated.

12. Diversity of Form, or Habit. — While in the crystals of a given species there is constancy of angle between like faces, the forms of the crystals may be exceedingly diverse. The accompanying figures (5–8) are examples of a few of the forms of the species zircon. There is hardly any limit to the number of faces which may occur, and as their relative size changes, the *habit*, as it is called, may vary indefinitely.

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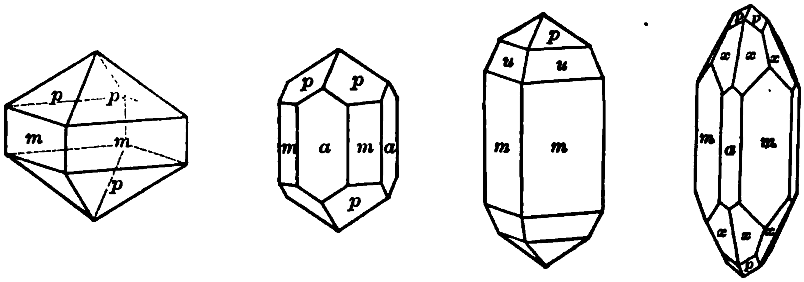

Zircon

13. Diversity of Size. — Crystals occur of all sizes, from the merest microscopic point to a yard or more in diameter. It is important to understand, however, that in a minute crystal the development is as complete as with a large one. Indeed the highest perfection of form and transparency is found only in crystals of small size.

A single crystal of quartz, now at Milan, is three and a quarter feet long and five and a half in circumference, and its weight is estimated at eight hundred and seventy pounds. A single cavity in a vein of quartz near the Tiefen Glacier, in Switzerland, discovered in 1867, afforded smoky quartz crystals, a considerable number of which had a weight of 200 to 250 pounds. A gigantic beryl from Acworth, New Hampshire, measured four feet in length and two and a half in circumference; another, from Grafton, was over four feet long, and thirty-two inches in one of its diameters, and weighed about two and a half tons.

14. Symmetry in General. — The faces of a crystal are arranged according to certain laws of symmetry, and this symmetry is the natural basis of the division of crystals into systems and classes. The symmetry may be defined in relation to (1) *a plane of symmetry*, (2) *an axis of symmetry*, and (3) *a center of symmetry*.

These different kinds of symmetry may, or may not, be combined in the same crystal. It will be shown later that there is one class, the crystals of which have neither center, axis, nor plane of symmetry; another where there is only a center of symmetry. On the other hand, some classes have all these elements of symmetry represented.

15. Planes of Symmetry. — A solid is said to be geometrically * symmetrical with reference to a plane of symmetry when for each face, edge, or solid angle there is another similar face, edge, or angle which has a like position with reference to this plane. Thus it is obvious that the crystal of amphibole, shown in Fig. 9, is symmetrical with reference to the central plane of symmetry indicated by the shading.

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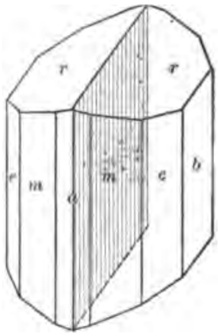
* The relation between the ideal geometrical symmetry and the actual crystallographic symmetry is discussed in Art. 18.

In the ideal crystal this symmetry is *right symmetry* in the geometrical sense, where every point on the one side of the plane of symmetry has a corresponding point at equal distances on the other side, measured on a line normal to it. In other words, in the ideal geometrical symmetry, one half of the crystal is the exact *mirror-image* of the other half.

9



Amphibole

A crystal may have as many as nine planes of symmetry, three of one set and six of another, as is illustrated by the cube * (Fig. 16). Here the planes of the first set pass through the crystal parallel to the cubic faces; they are shown in Fig. 10. The planes of the second set join the opposite cubic edges; they are shown in Fig. 11.

16. Axes of Symmetry. — If a solid can be revolved through a certain number of degrees about some line as an axis, with the result that it again occupies precisely the same position in space as at first, that axis is said to be an axis of symmetry. There are four different kinds of axes of symmetry among crystals; they are defined according to the number of times which the crystal repeats itself in appearance during a complete revolution of 360°.

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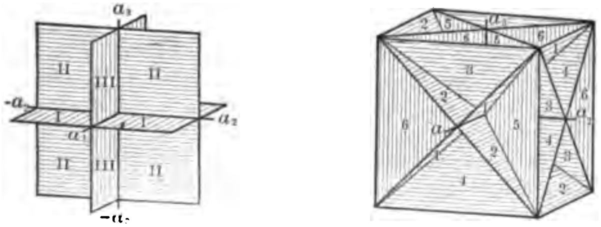

Symmetry Planes in the Cube

(*a*) A crystal is said to have an axis of *binary*, or *twofold*, symmetry when a revolution of 180° produces the result named above; in other words, when it repeats itself twice in a complete revolution. This is true of the crystal shown in Fig. 12 with respect to the vertical axis (and indeed each of the horizontal axes also).

(*b*) A crystal has an axis of *trigonal*, or *threefold*, symmetry when a revolution of 120° is needed; that is, when it repeats itself three times in a complete revolution. The vertical axis of the crystal shown in Fig. 13 is an axis of trigonal symmetry.

(*c*) A crystal has an axis of *tetragonal*, or *fourfold*, symmetry when a revolution of 90° is called for; in other words, when it repeats itself four times in a complete revolution. The vertical axis in the crystal shown in Fig. 14 is such an axis.

(*d*) Finally, a crystal has an axis of *hexagonal*, or *sixfold*, symmetry when a revolution of 60° is called for; in other words, when it repeats itself six times in a complete revolution. This is illustrated by Fig. 15.

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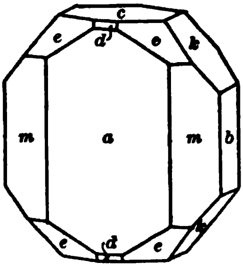
* This is the cube of the normal class of the isometric system.

The different kinds of symmetry axes are sometimes known as *diad*, *triad*, *tetrad* and *hexad* axes.



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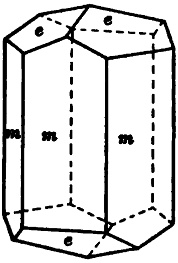
Chrysolite



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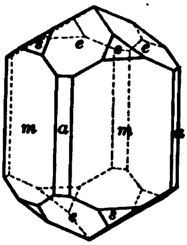
Calcite



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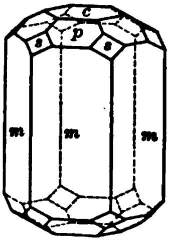
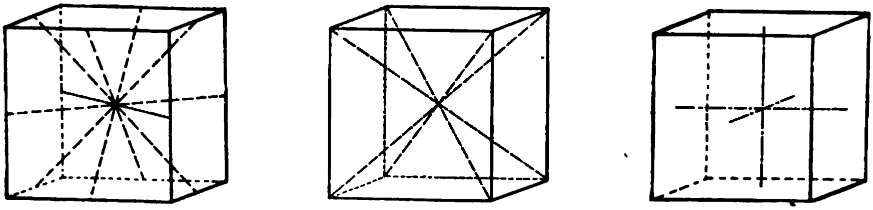
Rutile



15

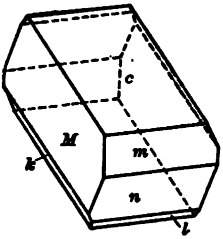
Beryl

The cube * illustrates three of the four possible kinds of symmetry with respect to axes of symmetry. It has six axes of *binary* symmetry joining the middle points of opposite edges (Fig. 16). It has four axes of *trigonal* symmetry, joining the opposite solid angles (Fig. 17). It has, finally, three axes of *tetragonal* symmetry joining the middle points of opposite faces (Fig. 18).


16 17 18

Symmetry Axes in the Cube

17. Center of Symmetry. — Most crystals, besides planes and axes of symmetry, have also a center of symmetry. On the other hand, a crystal, though possessing neither plane nor axis of symmetry, may yet be symmetrical with reference to a point, its center. This last is true of the triclinic crystal shown in Fig. 19, in which it follows that every face, edge, and solid angle has a face, edge, and angle similar to it in the opposite half of the crystal.



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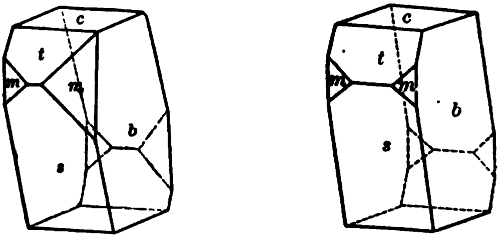
Rhodonite



20 21

Heulandite

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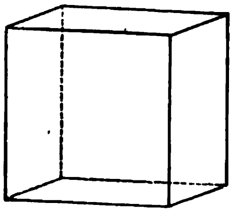
* This is again the cube of the normal class of the isometric system.

18. Relation of Geometrical to Crystallographic Symmetry. — Since the symmetry in the arrangement of the faces of a crystal is an expression of the internal molecular structure, which in general is alike in all parallel directions, the *relative size* of the faces and their *distance* from the plane or axis of symmetry are of no moment, their *angular position* alone is essential. The crystal represented in Fig. 20, although its faces show an unequal development, has in the crystallographic sense as truly a vertical plane of symmetry (parallel to the face *b*) as the ideally developed crystal shown in Fig. 21. The strict geometrical definition of symmetry would, however, apply only to the second crystal.*

22



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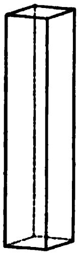

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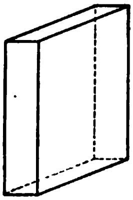
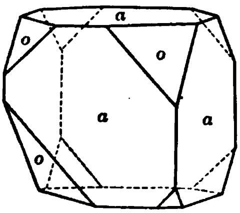


Cube

Distorted Cubes

Also in a normal cube (Fig. 22) the three central planes parallel to each pair of cubic faces are like planes of symmetry, as stated in Art. **15.** But a crystal is still crystallographically a cube, though deviating widely from the requirements of the strict geometrical definition, as shown in Figs. 23, 24, if only it can be proved, *e.g.*, by cleavage, by the physical nature of the faces, or by optical means, that the three pairs of faces are *like* faces, independently of their size, or, in other words, that the molecular structure is the same in the three directions normal to them.

25



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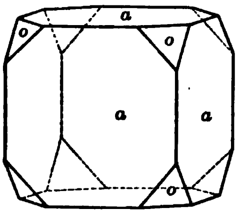

Cube and Octahedron

Further, in the case of a normal cube, a face of an octahedron on any solid angle requires, as explained beyond, similar faces on the other angles. It is *not* necessary, however, that these eight faces should be of equal size, for in the crystallographic sense Fig. 25 is as truly symmetrical with reference to the planes named as Fig. 26.

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* It is to be noted that the perspective figures of crystals usually show the geometrically ideal form, in which like faces, edges, and angles have the same shape, size, and position. In other words, the ideal crystal is uniformly represented as having the symmetry called for by the strict geometrical definition.

19. On the other hand, the molecular and hence the crystallographic symmetry is not always that which the geometrical form would suggest. Thus, deferring for the moment the consideration of pseudo-symmetry, an illustration of the fact stated is afforded by the cube. It has already been implied and will be fully explained later that while the cube of the normal class of the isometric system has the symmetry described in Arts. **15, 16,** a cube of the same geometrical form but belonging molecularly, for example, to the tetrahedral class, has no planes of symmetry parallel to the faces but only the six diagonal planes; further, though the four axes shown in Fig. 17 are still axes of trigonal symmetry, the cubic axes (Fig. 18) are axes of binary symmetry only, and there are no axes of symmetry corresponding to those represented in Fig. 16. Other more complex cases will be described later.

Further, a crystal having interfacial angles of 90° is not necessarily a cube: in other words, the angular relations of the faces do not show in this case whether the figure is bounded by six like faces; or whether only four are alike and the other pair unlike; or, finally, whether there are three pairs of unlike faces. The question must be decided, in such cases, by the molecular structure as indicated by the physical nature of the surfaces, by the cleavage, or by other physical characters, as pyro-electricity, those connected with light phenomena, etc.

Still, again, the student will learn later that the decision reached in regard to the symmetry to which a crystal belongs, based upon the *distribution* of the faces, is only preliminary and approximate, and before being finally accepted it must be confirmed, first, by accurate measurements, and, second, by a minute study of the other physical characters.

The method based upon the physical characters, which gives most conclusive results and admits of the widest application, is the skillful etching of the surface of the crystal by some appropriate solvent. By this means there are, in general, produced upon it minute depressions the shape of which conforms to the symmetry in the arrangement of the molecules. This process, which is in part essentially one involving the dissection of the molecular structure, is more particularly discussed in the chapter on Physical Mineralogy.

20. Pseudo-symmetry. — The crystals of certain species approximate closely in angle, and therefore in apparent symmetry, to the requirements of a system higher in symmetry than that to which they actually belong: they are then said to exhibit *pseudo-symmetry.* Numerous examples are given under the different systems. Thus the micas have been shown to be truly monoclinic in crystallization, though in angle they seem to be in some cases rhombohedral, in others orthorhombic.

It will be shown later that compound, or twin, crystals may also simulate by their regular grouping a higher grade of symmetry than that which belongs to the single crystal. Such crystals also exhibit pseudo-symmetry and are specifically called *mimetic.* Thus aragonite is an example of an orthorhombic species, whose crystals often imitate by twinning those of the hexagonal system.* Again, a highly complex twinned crystal of the monoclinic species, phillipsite, may have nearly the form of a rhombic dodecahedron of the isometric system. This kind of pseudo-symmetry also occurs among the classes of a single system, since a crystal belonging to a class of low symmetry may by twinning gain the geometrical symmetry of the corresponding form of the normal class. This is illustrated by a twinned crystal of scheelite like that figured (Fig. 416) in the chapter on twin crystals.

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* The terms *pseudo-hexagonal,* etc., used in this and similar cases explain themselves.

Pseudo-symmetry of still another kind, where there is an imitation of the symmetry of another system of lower grade, is particularly common in crystals of the isometric system (*e.g.*, gold, copper). The result is reached in such cases by an abnormal development of "distortion" in the direction of certain axes of symmetry. This subject is discussed and illustrated on a later page.

21. Possible Classes of Symmetry. — The theoretical consideration of the different kinds of symmetry possible among crystals built up of like molecules, as explained in Arts. **30–32,** has led to the conclusion that there are thirty-two (32) types in all, differing with respect to the combination of the different symmetry elements just described. Of these thirty-two natural classes among crystals based upon their symmetry, seven classes include by far the larger number of crystallized minerals. Besides these, some thirteen or fourteen others are distinctly represented, though several of these are of rare occurrence. The remaining classes, with possibly one or two exceptions, are known among the crystallized salts made in the laboratory. The characters of each of the thirty-two classes are given under the discussion of the several crystalline systems.

22. Crystallographic Axes. — In the description of a crystal, especially as regards the position of its faces, it is found convenient to assume, after the methods of analytical geometry, certain lines passing through the center of the ideal crystal, as a basis of reference. (See further Art. **34** *et seq.*)

These lines are called the *crystallographic axes.* Their direction is to a greater or less extent fixed by the symmetry of the crystals, for an axis of symmetry is in almost all cases * a possible crystallographic axis. Further, the unit lengths assigned to these axes are fixed sometimes by the symmetry, sometimes by the position of the faces assumed as fundamental, *i.e.*, the unit forms in the sense defined later. The broken lines shown in Fig. 18 are the crystallographic axes to which the cubic faces are referred.

23. Systems of Crystallization. — The thirty-two possible crystal classes which are distinguished from one another by their symmetry, are classified in this work under six systems, each characterized by the relative lengths and inclinations of the assumed crystallographic axes. These are as follows:

I. ISOMETRIC SYSTEM. Three equal axes at right angles to each other.

II. TETRAGONAL SYSTEM. Three axes at right angles to each other, two of them — the horizontal axes — equal, the third — the vertical axis — longer or shorter.

III. HEXAGONAL SYSTEM. Four axes, three equal horizontal axes in one plane intersecting at angles of 60°, and a vertical axis at right angles to this plane and longer or shorter.

IV. ORTHORHOMBIC SYSTEM. Three axes at right angles to each other, but all of different lengths.

V. MONOCLINIC SYSTEM. Three axes unequal in length, and having one of their intersections oblique, the two other intersections equal to 90°.

VI. TRICLINIC SYSTEM. Three unequal axes with mutually oblique intersections.

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* Exceptions are found in the isometric system, where the axes must necessarily be the axes of tetragonal symmetry (Fig. 18), and cannot be those of binary or trigonal symmetry (Figs. 16, 17).

24. Each one of the six systems, as will be understood from Art. 21, embraces several classes differing among themselves in their symmetry. One of these classes is conveniently called the *normal* class, since it is in general the common one, and since further it exhibits the highest degree of symmetry possible for the given system, while the others are lower in grade of symmetry.

It is important to note that the classes comprised within a given system are at once essentially connected together by their common optical characters, and in general separated * from those of the other systems in the same way.

Below is given a list of the six systems together with their subordinate classes, thirty-two in all. The order and the names given first are those that are used in this book while in the following parentheses are given other equivalent names that are also in common use. Under nearly all of the classes it is possible to give the name of a mineral or an artificial compound whose crystals serve to illustrate the characters of that particular class. There is some slight variation between different authors in the order in which the crystal systems and classes are considered but in the main essentials all modern discussions of crystallography are uniform.

ISOMETRIC SYSTEM

(*Regular, Cubic System*)

1. NORMAL CLASS. (Hexoctahedral. Holohedral.) Galena Type.
2. PYRITOHEDRAL CLASS. (Dyakisdodecahedral. Pentagonal Hemihedral.) Pyrite Type.
3. TETRAHEDRAL CLASS. (Hextetrahedral. Tetrahedral Hemihedral.) Tetrahedrite Type.
4. PLAGIOHEDRAL CLASS. (Pentagonal Icositetrahedral. Plagiohedral Hemihedral.) Cuprite Type.
5. TETARTOHEDRAL CLASS. (Tetrahedral Pentagonal Dodecahedral.) Sodium Chlorate Type.

TETRAGONAL SYSTEM

6. NORMAL CLASS. (Ditetragonal Bipyramidal. Holohedral.) Zircon Type.
7. HEMIMORPHIC CLASS. (Ditetragonal Pyramidal. Holohedral Hemimorphic.) Iodosuccinimide Type.
8. TRIPYRAMIDAL CLASS. (Tetragonal Bipyramidal. Pyramidal Hemihedral.) Scheelite Type.
9. PYRAMIDAL-HEMIMORPHIC CLASS. (Tetragonal Pyramidal. Hemihedral Hemimorphic.) Wulfenite Type.
10. SPHENOIDAL CLASS. (Tetragonal Sphenoidal. Sphenoidal Hemihedral. Scalenohedral.) Chalcopyrite Type.
11. TRAPEZOHEDRAL CLASS. (Tetragonal Trapezohedral. Trapezohedral Hemihedral.) Nickel Sulphate Type.
12. TETARTOHEDRAL CLASS. (Tetragonal Bisphenoidal.) Artif. $2\,CaO.Al_2O_3.SiO_2$ Type.

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* Crystals of the tetragonal and hexagonal systems are alike in being optically uniaxial; but the crystals of all the other systems have distinguishing optical characters.

HEXAGONAL SYSTEM

A. Hexagonal Division

13. **Normal Class.** (Dihexagonal Bipyramidal. Holohedral.) Beryl Type.
14. **Hemimorphic Class.** (Dihexagonal Pyramidal. Holohedral Hemimorphic.) Zincite Type.
15. **Tripyramidal Class.** (Hexagonal Bipyramidal. Pyramidal Hemihedral.) Apatite Type.
16. **Pyramidal-Hemimorphic Class.** (Hexagonal Pyramidal. Pyramidal Hemihedral Hemimorphic.) Nephelite Type.
17. **Trapezohedral Class.** (Hexagonal Trapezohedral. Trapezohedral Hemihedral.) β-Quartz Type.

B. Trigonal or Rhombohedral Division

(*Trigonal System*)

18. **Trigonal Class.** (Ditrigonal Bipyramidal. Trigonal Hemihedral.) Benitoite Type.
19. **Rhombohedral Class.** (Ditrigonal Scalenohedral. Rhombohedral Hemihedral.) Calcite Type.
20. **Rhombohedral Hemimorphic Class.** (Ditrigonal Pyramidal. Trigonal Hemihedral Hemimorphic.) Tourmaline Type.
21. **Tri-Rhombohedral Class.** (Rhombohedral. Rhombohedral Tetartohedral.) Phenacite Type.
22. **Trapezohedral Class.** (Trigonal Trapezohedral. Trapezohedral Tetartohedral.) Quartz Type.
23. (Trigonal Bipyramidal. Trigonal Tetartohedral.
24. (Trigonal Pyramidal. Trigonal Tetartohedral Hemimorphic.) Sodium Periodate Type.

ORTHORHOMBIC SYSTEM

(*Rhombic or Prismatic System*)

25. **Normal Class.** (Orthorhombic Bipyramidal. Holohedral.) Barite Type.
26. **Hemimorphic Class.** (Orthorhombic Pyramidal.) Calamine Type.
27. **Sphenoidal Class.** (Orthorhombic Bisphenoidal.) Epsomite Type.

MONOCLINIC SYSTEM

(*Oblique System*)

28. **Normal Class.** (Prismatic. Holohedral.) Gypsum Type.
29. **Hemimorphic Class.** (Sphenoidal.) Tartaric Acid Type.
30. **Clinohedral Class.** (Domatic. Hemihedral.) Clinohedrite Type.

TRICLINIC SYSTEM

(*Anorthic System*)

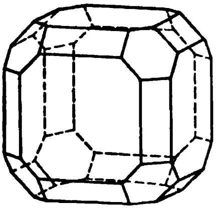
31. **Normal Class.** (Holohedral. Pinacoidal.) Axinite Type.
32. **Asymmetric Class.** (Hemihedral.) Clacium Thiosulphate Type.

25. Symmetry of the Systems. — In the paragraphs immediately following, a synopsis is given of the symmetry of the *normal class* of each of the different systems, and also that of one subordinate class of the hexagonal system, which is of so great importance that it is also often conveniently treated as a sub-system even when, as in this work, the forms are referred to the same axes as those of the strictly hexagonal type — a usage not adopted by all authors.

I. ISOMETRIC SYSTEM. Three like axial * planes of symmetry (principal planes) parallel to the cubic faces, and fixing by their intersection the crystallographic axes; six like diagonal planes of symmetry, passing through each opposite pair of cubic edges, and hence parallel to the faces of the rhombic dodecahedron.

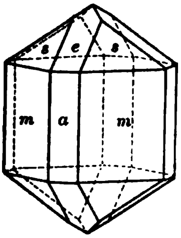
Further, three like axes of tetragonal symmetry, the crystallographic axes normal to the faces of the cube; four like diagonal axes of trigonal symmetry, normal to the faces of the octahedron; and six like diagonal axes of binary symmetry, normal to the faces of the dodecahedron. There is also obviously a center of symmetry.† These relations are illustrated by Fig. 27 also by Fig. 35; further by Figs. 92 to 125.

27



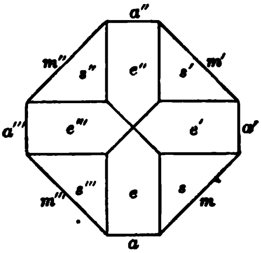
Galena

28



Rutile

29



Rutile

II. TETRAGONAL SYSTEM. Three axial planes of symmetry: of these, two are like planes intersecting at 90° in a line which is the vertical crystallographic axis, and the third plane (a principal plane) is normal to them and hence contains the horizontal axes. There are also two diagonal planes of symmetry, intersecting in the vertical axis and meeting the two axial planes at angles of 45°.

Further, there is one axis of tetragonal symmetry, a principal axis; this is the vertical crystallographic axis. There are also in a plane normal to this four axes of binary symmetry — like two and two — those of each pair at right angles to each other. Fig. 28 shows a typical tetragonal crystal, and Fig. 29 a basal projection of it, that is, a projection on the principal plane of symmetry normal to the vertical axis. See also Fig. 36 and Figs. 170–192.

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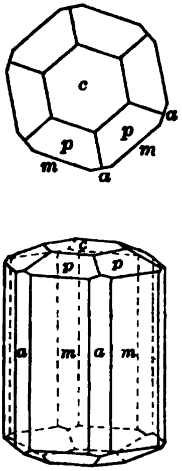
* Two planes of symmetry are said to be *like* when they divide the ideal crystal into halves which are identical to each other; otherwise, they are said to be *unlike*. Axes of symmetry are also like or unlike. If a plane of symmetry includes two of the crystallographic axes, it is called an *axial plane* of symmetry. If the plane includes two or more like axes of symmetry, it is called a *principal plane* of symmetry; also an axis of symmetry in which two or more like planes of symmetry meet is a *principal axis* of symmetry.

† In describing the symmetry of the different classes, here and later, the center of symmetry is ordinarily not mentioned when its presence or absence is obvious.

III. Hexagonal System. In the *Hexagonal Division* there are four axial planes of symmetry; of these three are like planes meeting at angles of 60°, their intersection-line being the vertical crystallographic axis; the fourth plane (a principal plane) is at right angles to these. There are also three other diagonal planes of symmetry meeting the three of the first set in the vertical axis, and making with them angles of 30°.

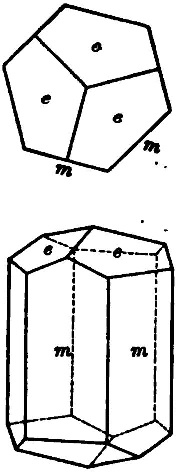
Further, there is one principal axis of hexagonal symmetry; this is the vertical crystallographic axis; at right angles to it there are also six binary axes. The last are in two sets of three each. Fig. 30 shows a typical hexagonal crystal, with a basal projection of the same. See also Fig. 37 and Figs. 220–227.

30



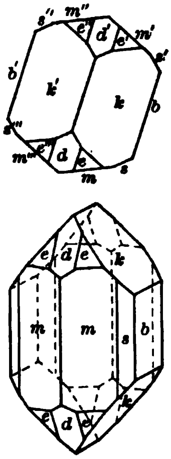
Microsommite

31



Calcite

32



Chrysolite

In the *Trigonal* or *Rhombohedral Division* of this system there are three like planes of symmetry intersecting at angles of 60° in the vertical axis. Further, the forms belonging here have a vertical principal axis of trigonal symmetry, and three horizontal axes of binary symmetry, coinciding with the horizontal crystallographic axes. Fig. 31 shows a typical rhombohedral crystal, with its basal projection. See also Figs. 243–269.

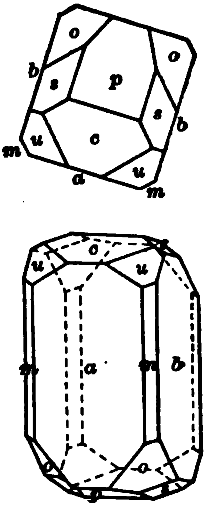
IV. Orthorhombic System. Three unlike planes of symmetry meeting at 90°, and fixing by their intersection-lines the position of the crystallographic axes. Further, three unlike axes of binary symmetry coinciding with the last-named axes. Fig. 32 shows a typical orthorhombic crystal, with its basal projection. See also Fig. 38 and Figs. 298–320.

V. Monoclinic System. · One plane of symmetry which contains two of the crystallographic axes. Also one axis of binary symmetry, normal to this plane and coinciding with the third crystallographic axis. See Fig. 33; also Fig. 39 and Figs. 333–347.

VI. Triclinic System. No plane and no axis of symmetry, but symmetry solely with respect to the central point. Figs. 34 and 40 show typical triclinic crystals. See also Figs. 359–366

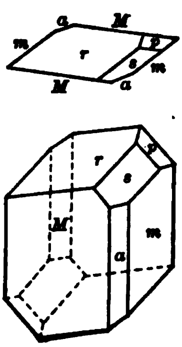
26. The relations of the normal classes of the different systems are further illustrated both as regards the crystallographic axes and symmetry by the accompanying figures, 35–40. The exterior form is here that bounded by faces each of which is parallel to a plane through two of the crystallographic axes indicated by the central broken lines. Further, there is shown, within this, the combination of faces each of which joins the extremities of the unit lengths of the axes.

33



Pyroxene

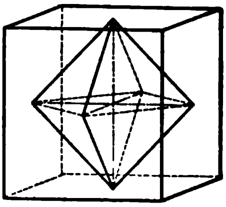
34



Axinite

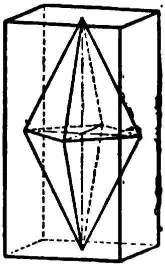
The full understanding of the subject will not be gained until after a study of the forms of each system in detail. Nevertheless the student will do well to make himself familiar at the outset with the fundamental relations here illustrated.

35



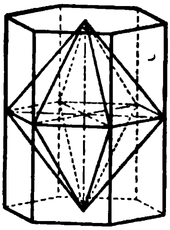
Isometric

36



Tetragonal

37

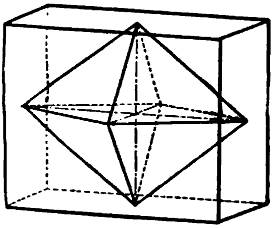


Hexagonal

It will be shown later that the symmetry of the different classes can be most clearly and easily exhibited by the use of the different projections explained in Art. 39 *et seq.*

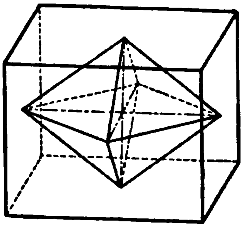
27. Models. — Glass (or transparent celluloid) models illustrating the different systems, having the forms shown in Figs. 35–40, will be very useful to the student, especially in learning the fundamental relations as regards symmetry. They should show within, the crystallographic axes, and by colored threads or wires, the outlines of one or more simple forms. Models of wood are also made in great variety and perfection of form; these are indispensable to the student in mastering the principles of crystallography.

38



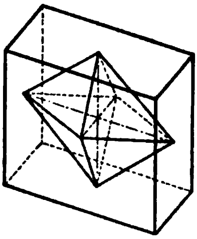
Orthorhombic

39



Monoclinic

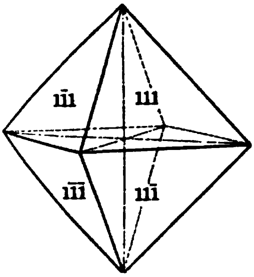
40



Triclinic

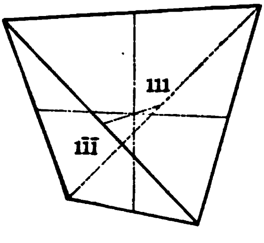
28. So-called Holohedral and Hemihedral Forms. — It will appear later that each crystal form * of the normal class in a given system embraces *all* the faces which have a like geometrical position with reference to the crystallographic axes; such a form is said to be *holohedral* (from ὅλος, complete, and ἕδρα, face). On the other hand, under the classes of lower symmetry, a certain form, while necessarily having all the faces which the symmetry allows, may yet have but *half* as many as the corresponding form of the normal class; these half-faced forms are sometimes called on this account *hemihedral.* Furthermore, it will be seen that, in such cases, to the given holohedral form there correspond two similar and complementary hemihedral forms, called respectively positive and negative (or right and left), which together embrace all of its faces.

41



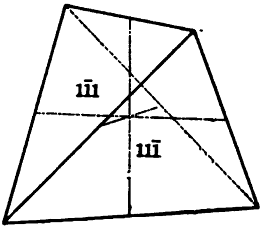
Octahedron

42



Positive Tetrahedron

43



Negative Tetrahedron

A single example will help to make the above statement intelligible. In the normal class of the isometric system, the octahedron (Fig. 41) is a "holohedral" form with all the possible faces — eight in number — which are alike in that they meet the axes at equal distances. In the tetrahedral class of the same system, the forms are referred to the same crystallographic axes, but the symmetry defined in Art. 19 (and more fully later) calls for but four similar faces having the position described. These yield a four-faced, or "hemihedral," form, the tetrahedron. Figures 42 and 43 show the positive and negative tetrahedron, which together, it will be seen, embrace all the faces of the octahedron, Fig. 41.

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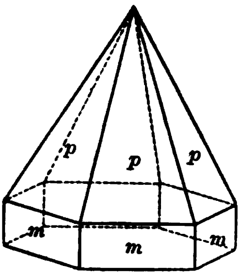
* The use of the word *form* is defined in Art. 37

In certain classes of still lower symmetry a given crystal form may have ut *one-quarter* of the faces belonging to the corresponding normal form, and, after the same method, such a form is sometimes called *tetartohedral.*

The development of the various possible kinds of hemihedral (and tetartohedral) forms under a given system has played a prominent part in the crystallography of the past, but it leads to much complexity and is distinctly less simple than the direct statement of the symmetry in each case. The latter method is systematically followed in this work, and the subject of hemihedrism is dismissed with the brief (and incomplete) statements of this and the following paragraphs.

29. Hemimorphic Forms. — In several of the systems, forms occur under the classes of lower symmetry than that of the normal class which are characterized by this: that the faces present are only those belonging to one extremity of an axis of symmetry (and crystallographic axis). Such forms are conveniently called *hemimorphic* (*half-form*). A simple example under the hexagonal system is given in Fig. 44. It is obvious that hemimorphic forms have no center of symmetry.

44



Zincite

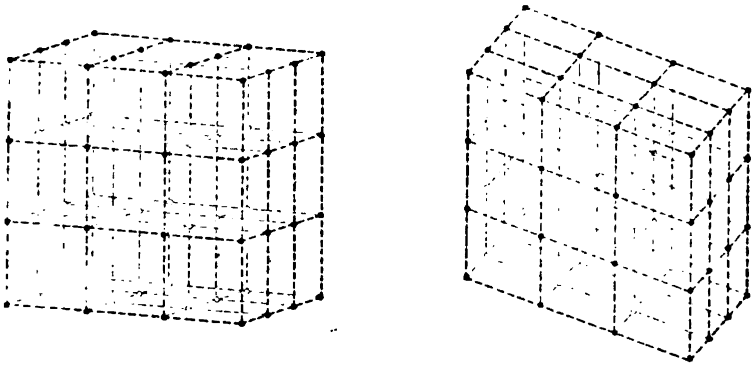
30. Molecular Networks. — Much light has recently been thrown upon the relations existing between the different types of crystals, on the one hand, and of these to the physical properties of crystals, on the other, by the consideration of the various possible methods of grouping of the molecules of which the crystals are supposed to be built up. This subject, very early treated by Haüy and others (including J. D. Dana), was discussed at length by Frankenheim and later by Bravais. More recently it has been extended and elaborated by Sohncke, Wulff, Schönflies, Fedorow, Barlow, and others.

All solid bodies, as stated in Art. 7, are believed to be made up of definite physical units, called the physical, or crystal, molecules. Of the form of the molecules nothing is definitely known, and though theory has something to say about their size, it is enough here to understand that they are almost infinitely small, so small that the surface of a solid — *e.g.*, of a crystal — may appear to the touch and to the eye, even when assisted by a powerful microscope, as perfectly smooth.

The molecules are further believed to be not in contact but separated from one another — if in contact, it would be impossible to explain the motion to which the sensible heat of the body is due, or the transmission of radiation (radiant heat and light) through the mass by the wave motion of the ether, which is believed to penetrate the body.

When a body passes from the state of a liquid or a gas to that of a solid, under such conditions as to allow perfectly free action to the forces acting between the molecules, the result is a crystal of some definite type as regards symmetry. The simplest hypothesis which can be made assumes that the form of the crystal is determined by the way in which the molecules group themselves together in a position of equilibrium under the action of the intermolecular forces.

As, however, the forces between the molecules vary in magnitude and direction from one type of crystal to another, the resultant grouping of the molecules must also vary, particularly as regards the distance between them or the angles between the planes in which they lie. This may be simply represented by a series of geometrical diagrams, showing the hypothetical groupings of points which are strictly to be regarded as the centers of gravity of the molecules themselves. Such a grouping is named a *network*, or point-system; and it is said to be *regular* when it is the same for all parallel lines or planes, however they be taken. For the fundamental observed fact, true of all simple crystals, that they have like physical properties in all parallel directions, leads to the conclusion that the grouping of the molecules must be the same about each one of them (or at least about each unit group of them), and further the same in all parallel lines and planes.



45 **46**

Crystal Networks

The subject may be illustrated by Figs. 45, 46 for two typical cases, which are easily understood. In Fig. 45 the most special case is represented where the points are grouped at equal distances, in planes at right angles to each other. The structure in this case obviously corresponds in symmetry to the one described in Arts. **15** and **16**, or, in other words, to the normal class of the isometric system. Again, in Fig. 46, the general case is shown where the molecules are unequally grouped in the three directions, and further these directions are oblique. The symmetry is here that of the normal class of the triclinic system.

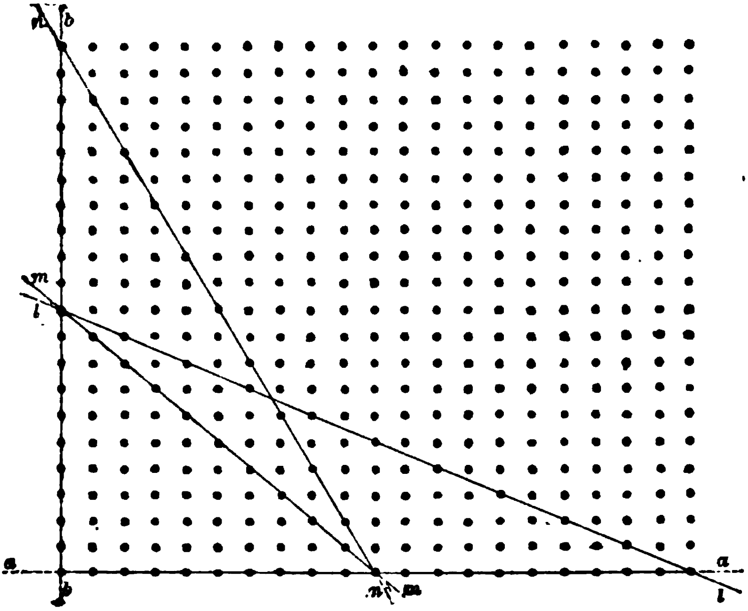
If, in each of these cases, the figure be bounded by the simplest possible arrangement of eight points, the result is an *elementary parallelopiped*, which obviously defines the molecular structure of the whole. In the grouping of these parallelopipeds together, as described, it is obvious that in whatever direction a line be drawn through them, the points (molecules) will be spaced alike along it, and the grouping about any one of these points will be the same as about any other.

31. Certain important conclusions can be deduced from a consideration of such regular molecular networks as have been spoken of, which will be enumerated here though it is impossible to attempt a full explanation.

(1) The prominent crystalline faces must be such as include the largest number of points, that is, those in which the points are nearest together.

Thus in Fig. 47, which represents a section of a network conforming in symmetry to the structure of a normal orthorhombic crystal, the common crystalline faces would be expected to be those having the position *bb*, *aa*, *mm*, then *ll*, *nn*, and so on. This is found to be true in the study of crystals, for the common forms are, in nearly all cases, those whose position bears some simple relation to the assumed axes; forms whose position is complex are usually present only as small faces on the simple predominating forms, that is, as modifications of them So-called *vicinal* forms, that is, forms taking the place of the simple fundamental forms to which they approximate very closely in angular position, are exceptional.

47



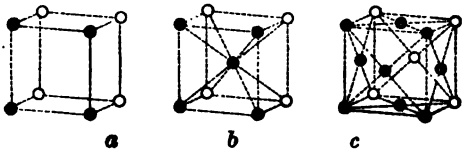
Orthorhombic Point System

(2) When a variety of faces occur on the same crystal, the numerical relation existing between them (that which fixes their position) must be rational and, as stated in (1), a simple numerical ratio is to be expected in the common cases. This as explained later, is found by experience to be a fundamental law of all crystals. Thus, in Fig. 47, starting with a face meeting the section in *mm*, *ll* would be a common face, and for it the ratio is 1 : 2 in the directions *b* and *a*; *nn* would be also common with the ratio 2 : 1.

(3) If a crystal shows the natural easy fracture, called cleavage, due to a minimum of cohesion, the cleavage surface must be a surface of relatively great molecular crowding, that is, one of the common or fundamental faces. This follows (and thus gives a partial, though not complete, explanation of cleavage) since it admits of easy proof that that plane in which the points are closest together is farthest separated from the next molecular plane. Thus in Fig 47 compare the distance separating two adjoining planes parallel to *bb* or *aa*, then two parallel to *mm*, *ll*, *nn*, etc Illustrations of the above will be found under the special discussion of the subject of cleavage.

32. Kinds of Molecular Groupings. — The discussion on the basis just described shows that there are fourteen possible types of arrangement of the molecules. These agree as to their symmetry with the seven classes defined in Art. **25** as representing respectively the normal classes of the six systems with also that of the trigonal (or the rhombohedral) division of the hexagonal system. Of the fourteen, three groupings belong to the isometric system (these are shown, for sake of illustration, in Fig. 48 from Groth; *a*, cube lattice; *b*, cube-centered lattice; *c*, face centered cube lattice); two to the tetragonal; one each to the hexagonal and the rhombohedral; four to the orthorhombic system; two to the monoclinic, and one to the triclinic.

48



Isometric Lattices

In its simplest form, as above outlined, the theory fails to explain the existence of the classes under the several systems of a symmetry lower than that of the normal class. It has been shown, however, by Sohncke and later by Fedorow, Schönflies and Barlow, that the theory admits of extension. The idea supposed by Sohncke is this: that, instead of the simple form shown, the network may consist of a double system, one of which may be conceived of as having a position relative to the other (1) as if pushed to one side, or (2) as if rotated about an axis, or finally (3) as if both rotated as in (2) and displaced as in (1) The complexity of the subject makes it impossible to develop it here. It must suffice to say that with this extension Sohncke concludes that there are 65 possible groups. This number has been further extended to 230 by the other authors named, but it still remains true that these fall into 32 distinct types as regards symmetry, and thus all the observed groups of forms among crystals, described under the several systems, have a theoretical explanation.

Literature. — A complete understanding of this subject can only be gained by a careful study of the many papers devoted to it. An excellent and very clear summary of the whole subject is given by Groth in the fourth edition of his Physikalische Krystallographie, 1905, and by Sommerfeldt, in his Physikalische Kristallographie, 1907.

33. X-Rays and Crystal Structure. — In 1912, while attempting to prove a similarity in character between X-rays and light, Dr. Laue, of the University of Zurich conceived the idea of using the ordered arrangement of the molecules or atoms of a crystal as a "diffraction grating" for their analysis By placing a photographic plate behind a crystal section which in turn lay in the path of a beam of X-rays he found that not only did the developed plate show a dark spot in its center where the direct pencil of the X-rays had hit it but it also showed a large number of smaller spots arranged around the center in a regular geometrical pattern. This pattern was formed by the interference of waves which had been diffracted in different directions by the molecular structure of the crystal. In this way he succeeded in proving that X-rays belong to the same class of phenomena as light but with a much shorter wave length. The experiment showed indeed that the wave lengths of the X-rays must be comparable to the distances between the layers of molecular particles of crystals. Another, and, from the crystallographic point of view, a very important, result of this investigation was the furnishing of a method for the study of the internal structure of crystals. The position of the smaller dark spots in the Laue photographs corresponded to that of various planes existing in the crystal network parallel to possible crystal faces and their arrangement indicated the symmetry of the crystal.

Following these investigations of Laue and his colleagues another fruitful method of investigation of crystal structure by means of X-rays was devised by W. H. and W. L. Bragg. In this method the beam of X-rays meets the crystal section with varying acute angles of incidence and the reflection of the rays is studied. The X-rays are not reflected from the surface of the section like light rays but because of their short wave lengths penetrate the crystal section and are reflected from the successive layers of its molecular structure. In studying the reflection phenomena we have to consider the effect upon each other of these different wave trains originating from the different layers of the crystal. In general these various reflected waves would be in different phases of vibration and so would tend to interfere with each other with the consequent cessation of all vibrations. But with a certain angle of incidence and reflection it would happen that the different reflected rays would possess on emergence from the crystal the same phase of vibration and would therefore reinforce each other. This angle would vary with the wave length of the X-ray used (for it has been found that the wave length of X-rays varies with the metal that is used as the anticathode in the X-ray bulb) and with the spacing between the molecular layers of the mineral used. It is also obvious that there might be other angles of incidence at which the successive wave trains would each differ in phase by two or even more whole wave lengths from the preceding one and a similar strong reflected beam obtained. By the use of a special X-ray spectrometer the angles at which these reflections take place can be accurately measured. If the character of the X-ray used is therefore kept constant these angles of reflection give the data necessary for calculating the distance between the successive molecular layers in the particular mineral used and for the direction perpendicular to the surface used for reflection. The spacing of the molecular layers was found to vary with different substances and in different directions in the same substance and by making a series of observations it has been possible to arrive at some very interesting conclusions as to the character of the molecular structure of certain minerals as well as to the relationship existing between the structures of different but related compounds. The possibilities lying in these methods of attack are very great and unquestionably much new information concerning crystal structure will soon be available. An excellent summary of the methods employed and the results already obtained will be found in "X-rays and Crystal Structure" by W. H. and W. L. Bragg, 1915.

GENERAL MATHEMATICAL RELATIONS OF CRYSTALS

34. Axial Ratio, Axial Plane. — The crystallographic axes have been defined (Art. **22**) as certain lines, usually determined by the symmetry, which are used in the description of the faces of crystals, and in the determination of their position and angular inclination. With these objects in view, certain lengths of these axes are assumed as units to which the occurring faces are referred.

The axes are, in general, lettered *a*, *b*, *c*, to correspond to the scheme in Fig. 49. If two of the axes are equal, they are designated *a*, *a*, *c*; if the three are equal, *a*, *a*, *a*. In one system, the hexagonal, there are four axes, lettered *a*, *a*, *a*, *c*.

Further, in the systems other than the isometric, one of the horizontal axes is taken as the *unit* to which the other axes are referred; hence the lengths of the axes express strictly the *axial ratio*. Thus for sulphur (orthorhombic, see Fig. 49) the axial ratio is

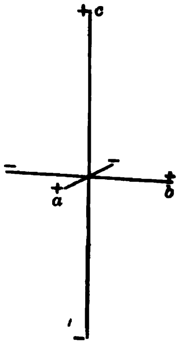
$$a : b : c = 0{\cdot}8131 : 1 : 1{\cdot}9034.$$

For rutile (tetragonal) it is

$$a : c = 1 : 0{\cdot}64415, \quad \text{or, simply,} \quad c = 0{\cdot}64415.$$

The plane of any two of the axes is called an *axial plane*, and the space included by the three axial planes is an *octant*, since the total space about the center is thus divided by the three axes into eight parts. In the hexagonal system, however, where there are three horizontal axes, the space about the center is divided into 12 parts, or *sectants*.

49

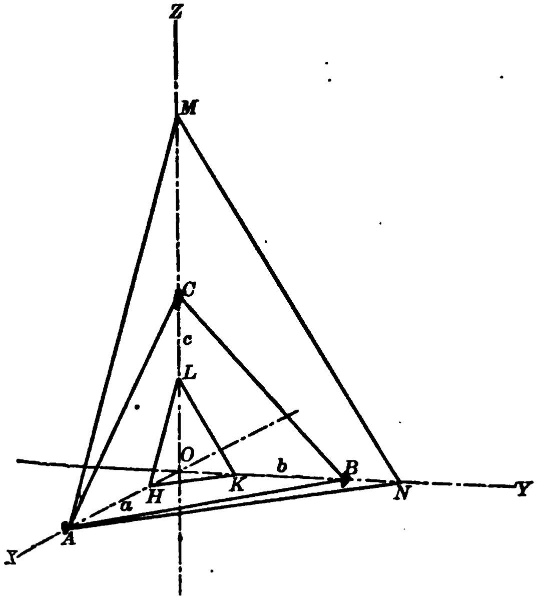


Orthorhombic Crystal Axes

35. Parameters, Indices, Symbol. — *Parameters.* The parameters of a plane consist of a series of numbers which express the relative intercepts of that plane upon the crystallographic axes. They are given in terms of the established unit lengths of those axes. For example, in Fig. 50 let the lines *OX*, *OY*, *OZ* be taken as the directions of the crystallographic axes, and let *OA*, *OB*, *OC* represent their unit lengths, designated (always in the same order) by the letters *a*, *b*, *c*. Then the intercepts for the plane (1) *HKL* are *OH*, *OK*, *OL*; for the plane (2) *ANM* they are *OA*, *ON*, *OM*. But in terms of the unit lengths of the axes these give the following parameters,

$$\begin{aligned} &(1) \quad \tfrac{1}{4}a : \tfrac{1}{3}b : \tfrac{1}{2}c \\ \text{and} \quad &(2) \quad 1a : \tfrac{4}{3}b : 2c. \end{aligned}$$

50



It is to be noted that since the two planes *HKL* and *MNA* are parallel to each other and hence crystallographically the same, these two sets of parameters are considered to be identical. Obviously each of them may be changed into the other by multiplying (or dividing) by 4.

Indices and Symbol. Simplified and abbreviated expressions which have been derived from the parameters of a crystal form are commonly used to give its relations to the crystallographic axes. These are known as indices. A number of different methods of deriving indices have been devised and several are in use at present. The so-called Miller indices are most widely employed and will be exclusively used in this work.* Below, a description of the other important systems of indices is given together with the necessary directions for transforming one type into another.

The Miller indices may be derived from the parameters of any form by taking their reciprocals and clearing of fractions if necessary. For instance take the two sets of parameters as given above.

$$(1)\quad \tfrac{1}{4}a : \tfrac{1}{3}b : \tfrac{1}{2}c, \quad \text{and} \quad (2)\quad 1a : \tfrac{4}{3}b : 2c.$$

By inversion of these expressions we obtain

$$(1)\quad 4a : 3b : 2c, \quad \text{and} \quad (2)\quad 1a : \tfrac{3}{4}b : \tfrac{1}{2}c.$$

In the case of (2) it is necessary to clear of fractions, giving

$$(2)\quad 4a : 3b : 2c.$$

The indices of this form then are $4\,a : 3\,b : 2\,c$. The letters indicating the different axes are commonly dropped and the indices in this case would be written simply as 432, the intercepts on the different axes being indicated by the order in which the numbers are given.

A general expression frequently used for the indices of a form belonging to any crystal system which has three crystallographic axes is *hkl*. In the hexagonal system, which has four axes, this becomes *hkil*. If the parameters of a form be written so that they are fractions with the numerators always unity then the denominators will become the same as the corresponding indices. The general expression in this case would therefore be $\frac{1}{h}\,\frac{1}{k}\,\frac{1}{l}$.

The *symbol* of a given form is the indices of the face of that form which has the simplest relations to the crystallographic axes. The symbol is commonly used to designate the whole form.

Various examples are given below illustrating the relations between parameters and indices.

Parameters		Miller's Symbol
$\frac{1}{2}a : \frac{1}{2}b : 1c$ $1a : 1b : 2c$	$= \frac{1}{2}a : \frac{1}{2}b : \frac{1}{1}c =$	221
$\frac{1}{2}a : 1b : \frac{1}{2}c$ $1a : 2b : 1c$	$= \frac{1}{2}a : \frac{1}{1}b : \frac{1}{2}c =$	212
$\frac{1}{2}a : \infty b : 1c$ $1a : \infty b : 2c$	$= \frac{1}{2}a : \frac{1}{0}b : \frac{1}{1}c =$	201
$\frac{1}{2}a : 1b : \infty c$ $1a : 2b : \infty c$	$= \frac{1}{2}a : \frac{1}{1}b : \frac{1}{0}c =$	210
$1a : \infty b : \infty c$	$= \frac{1}{1}a : \frac{1}{0}b : \frac{1}{0}c =$	100

If the axial intercepts are measured in behind on the *a* axis, or to the left on the *b* axis, or below on the *c* axis, they are called negative, and a minus sign is placed over the corresponding number of the indices; as

Parameters	Indices
$-\frac{1}{2}a : -\frac{1}{2}b : \frac{1}{1}c =$	$\bar{2}\bar{2}1$
$-\frac{1}{2}a : \frac{1}{0}b : \frac{1}{1}c =$	$\bar{2}01$

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* In the hexagonal system the indices used are those adapted by Bravais after the method of Miller.

Different Systems of Indices. The *Weiss* indices are the same as the parameters described above. The different axes are represented by the letters *a*, *b* and *c*, each being preceded by a number indicating the relative intercept of the face in question upon that particular axis. For instance, a possible orthorhombic pyramid face might be represented as $1a : 2b : \frac{2}{3}c$. The Weiss indices may be converted into the Miller indices by inversion and clearing of fractions, the above symbol becoming then 213. In the *Naumann* indices the unit pyramidal form is indicated by O in the isometric system where the three crystal axes all have the same unit lengths or by P where the axes differ in their unit lengths. For other forms the indices become *m*P*n* (or *m*O*n*) in which *m* gives the intercept upon the vertical axis, *c*, and *n* the intercept upon one of the horizontal axes (*a* or *b*), the intercept upon the other horizontal axis being always at unity. To which particular horizontal axis this number refers may be indicated by a mark over it as $\bar{n}$ for the *b* axis, $\breve{n}$ or n' for the *a* axis. If the intercept *m* or *n* is unity it is omitted from the indices. The pyramid face used as an example above would therefore in the Naumann notation be represented by $\frac{2}{3}$P2. Other examples are given in the table below. *J. D. Dana* modified the Naumann indices by substituting a hyphen for the letter P or O and *i* for the infinity sign, ∞. He designated the fundamental pyramid form simply by 1. When the only parameter differing from unity was that one which referred to the intercept upon the vertical axis, it was written alone; for example the pyramid face having the parameter relations of $1a : 1b : 2c$ would be indicated by 2. The Naumann and Dana indices are easily converted into the Miller indices by arranging them in the proper order, inverting and then clearing of fractions. *Goldschmidt* has proposed another method of deriving indices. This has the advantage that the indices for any particular face can be derived directly from the position of its pole on the gnomonic projection. The first number gives the linear position of the pole in respect to the left to right medial line of the projection and in terms of the unit pace distance of the projection (see Art. 84). The second figure similarly gives the position of the pole in reference to the front to back medial line. These two figures constitute the Goldschmidt indices of the face. If the two numbers should be the same the second is omitted. The Goldschmidt indices are easily converted into the Miller indices by adding 1 as the third figure and clearing of fractions and eliminating any ∞ sign.

The relations between the Miller and the Miller-Bravais indices for the hexagonal system are given in Art. 169.

EXAMPLES OF INDICES ACCORDING TO VARIOUS SYSTEMS OF NOTATION

Weiss	Naumann	Dana	Goldschmidt	Miller
$1a : 1b : 2c$	2P	2	2	221
$1a : 2b : 1c$	0P2	1–2	1½	212
$1a : \infty b : 2c$	2P∞	2–i	20	201
$1a : 2b : \infty c$	∞P2	i–2	2∞	210
$1a : \infty b : \infty c$	∞P∞	i–i	∞0	100

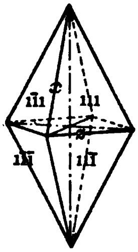
36. Law of Rational Indices. — The study of crystals has established the general law that the ratios between the intercepts on the axes for the different faces on a crystal can always be expressed by rational numbers. These ratios may be $1 : 2$, $2 : 1$, $2 : 3$, $1 : \infty$, etc., but never $1 : \sqrt{2}$, etc. Hence the values of *hkl* in the Miller symbols must always be either *whole numbers or zero.*

If the form whose intercepts on the axes *a*, *b*, *c* determine their assumed unit lengths — the *unit form* as it is called — is well chosen, these numerical values of the indices are in most cases very simple. In the Miller symbols, 0 and the numbers from 1 to 6 are most common.

The above law, which has been established as the result of experience, in fact follows from the consideration of the molecular structure as hinted at in an earlier paragraph (Art. 31).

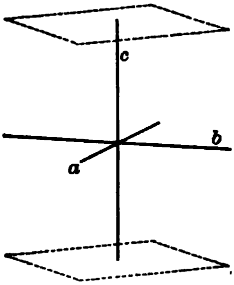
37. Form. — A *form* in crystallography includes *all* the faces which have a like position relative to the planes, or axes, of symmetry. The full meaning of this will be appreciated after a study of the several systems. It will be seen that in the most general case, that of a form having the symbol (*hkl*), whose planes meet the assumed unit axes at unequal lengths, there must be forty-eight like faces in the isometric system* (see Fig. 121), twenty-four in the hexagonal (Fig. 226), sixteen in the tetragonal (Fig. 187), eight in the orthorhombic (Fig. 51), four in the monoclinic, and two in the triclinic. In the first four systems the faces named yield an enclosed solid, and hence the form is called a *closed form;* in the remaining two systems this is not true, and such forms in these and other cases are called *open forms.* Fig. 298 shows a crystal bounded by three pairs of unlike faces; each pair is hence an open form. Figs. 52–55 show open forms.

51



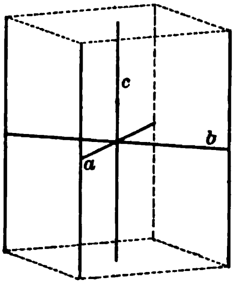
The *unit or fundamental form* is one where parameters correspond to the assumed unit lengths of the axes. Fig. 51 shows the unit pyramid of sulphur whose symbol is (111); it has eight similar faces, the position of which determines the ratio of the axes given in Art. **34.**

52



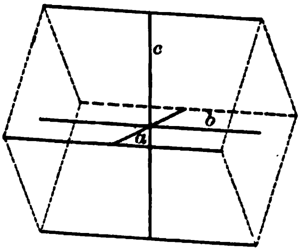
Basal Pinacoid
(001)

53



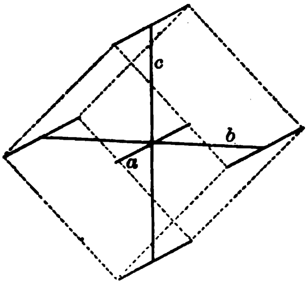
Prism
(110) (*hk*0)

54



Dome
(101), (*h*0*l*)

55



Dome
(011), (0*kl*)

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* The *normal* class is referred to in each case.

The forms in the isometric system have special individual names, given later. In the other systems certain general names are employed in this book which may be briefly mentioned here. A form whose faces are parallel to two of the axes * is called a *pinacoid* (from πίναξ, a board). It is shown in Fig. 52. One whose faces are parallel to the vertical axis but meet both the horizontal axes is called a *prism*, as Fig. 53. If the faces are parallel to one horizontal axis only, it is a *dome* (Figs. 54, 55). If the faces meet all the axes, the form is a *pyramid* (Fig. 51); this name is given even if there is only one face belonging to the form.

In Fig. 56, *a*(100), *b*(010) are pinacoids; *m*(110), *s*(120) are prisms; *d*(101) and *k*(021) are domes; all these are open forms. Finally, *e*(111) is a pyramid, this being a closed form. The relation existing in each of these cases between the symbol and the position of the faces to the axes should be carefully studied.

As shown in the above cases, the symbol of a *form* is usually included in parentheses, as (111), (100); or it may be in brackets [111] or {111}.

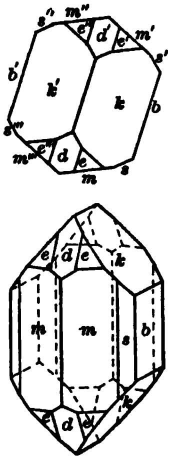
38. Zone. — A zone includes a series of faces on a crystal whose intersection-lines are mutually parallel to each other and to a common line drawn through the center of the crystal, called the *zone-axis*. This parallelism means simply that the given faces are either all parallel to one of the crystallographic axes or that their parameters have a constant ratio for two of the axes. Some simple numerical relation exists, in every case, between all the faces in a zone, which is expressed by the *zonal equation* (see Art. **45**). The faces *m*, *s*, *b* (Fig. 56) are in a zone; also, *b* and *k*.

If a face of a crystal falls simultaneously in two zones, it follows that its symbol is fixed and can be determined from the two zonal equations, without the measurement of angles. Further, it can be proved that the face corresponding to the intersection of two zones is always a possible crystal face, that is, one having rational values for the indices which define its position.

In many cases the zonal relation is obvious at sight, but it can always be determined, as shown in Arts. **45**, **46** by an easy calculation.

Illustrations will be given after the methods of representing a crystal by the various projections have been explained.

56



Chrysolite

39. Horizontal Projections. — In addition to the usual perspective figures of crystals, projections on the basal plane (or more generally the plane normal to the prismatic zone) are very conveniently used. These give in fact a map of the crystal as viewed from above looking in the direction of the axis of the prismatic zone. Figs. 30–33 give simple examples. In these the successive faces may be indicated by accents, as in Fig. 56, passing around in the direction of the axes *a*, *b*, $\bar{a}$, that is, counter-clockwise. On the construction of these projections see the Appendix A.

40. Spherical Projection. — The study of actual crystals, particularly as regards the angular and zonal relations of their faces, is much facilitated by the use of various projections. The simplest of these and the one from which the others may be derived is known as the *spherical projection*.

In making a spherical projection of a crystal it is assumed that the crystal lies within a sphere, the center of which coincides with the center of the crystal (*i.e.* the point of intersection of its crystallographic axes). From this common center normals are drawn to the successive faces of the crystal and continued until they meet the surface of the sphere. The points in which these normals touch that surface locate the poles of the respective faces and together form the spherical projection of the crystal. The method of formation and the character of the spherical projection is shown in Fig. 57.

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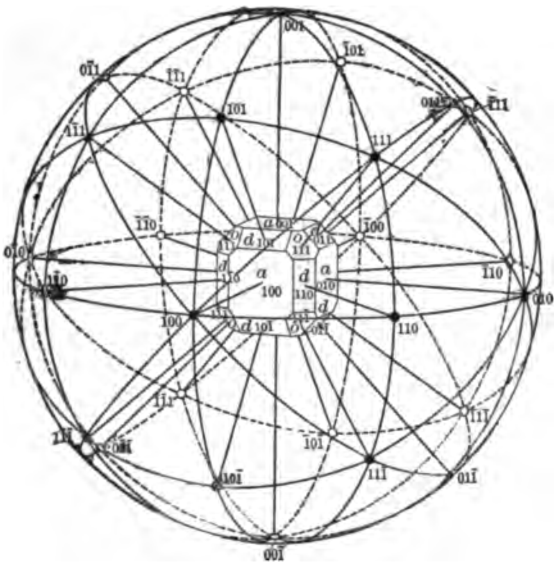
* In the tetragonal system the form (100) is, however, called a prism and (101) a pyramid.

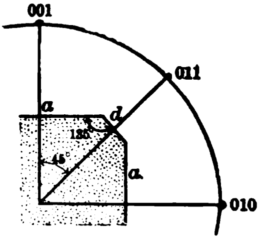
57



Spherical Projection (after Penfield)

It is to be noted that all the poles of faces which lie in the same zone on the crystal, *i.e.* faces whose intersection lines are mutually parallel, fall upon the same great circle on the sphere. This is illustrated in the figure in the case of the zone *a-d-a* and *a-o-d*. Conversely, of course, all faces whose poles fall on the same great circle of the spherical projection must lie in the same zone. A face whose pole falls at the intersection of two or more great circles lies in two or more independent zones, as for instance *o*(111), in Fig. 57. The angular relations between the faces on the crystal are of course preserved in the angles existing between their respective poles on the spherical projection. The angles between the poles, however, are the supplementary angles to those between the faces on the crystal, as shown in Fig. 58. The supplementary angles are those which are commonly measured and recorded when studying a crystal, see Art. **230.**

58



Cross-section of portion of Crystal and its Spherical Projection

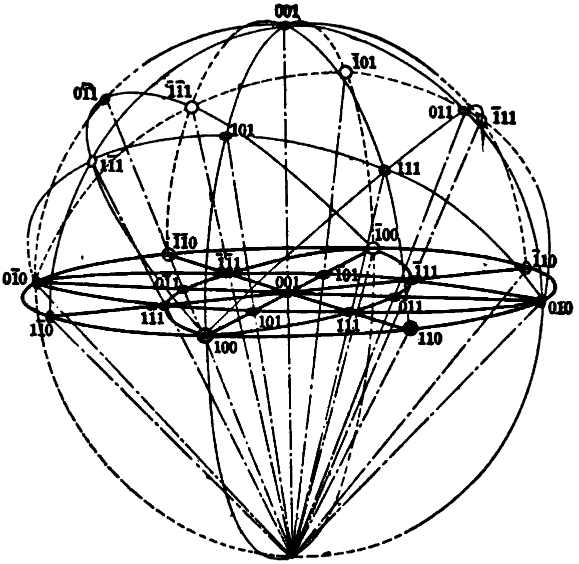
The spherical projection is very useful in getting a mental picture of the relations existing between the various faces and zones upon a crystal but because of its nature does not permit of the close study and accurate measurements that may be made on the other projections described below which are made on plane surfaces.

41. The Stereographic Projection. — The stereographic projection may be best considered as derived from the spherical projection in the following manner. The plane of the projection is commonly taken as the equatorial plane of the sphere. Imaginary lines are drawn from the poles of the spherical projection to the south pole of the sphere. The points in which these lines pierce the plane of the equator locate the poles in the stereographic projection. The relation between the two projections is shown in Fig. 59.

Fig. 60 shows the same stereographic projection without the foreshortening of Fig. 59. Commonly only the poles that lie in the northern hemisphere, including those on the equator, are transferred to the stereographic projection.

Certain facts concerning the stereographic projection need to be noted. Its most important character is that all circles or circular arcs on the spherical projection are projected as arcs of true circles on the stereographic projection.* The poles of all crystal faces that are parallel to the vertical crystallographic axis fall on the equator of the spherical projection and occupy the same positions in the stereographic projection. The pole of a horizontal face will fall on the center of the stereographic projection. All north and south meridians of the spherical projection will appear as straight radial lines in the stereographic projection (*i.e.* as arcs of circles having infinite radii). Other great circles on the spherical projection, as already stated, will be transferred to the stereographic as circular arcs. Examples of all these are shown in Fig. 60.

59



Relation between Spherical and Stereographic Projections

The angular relations between the poles of the various faces are preserved in the stereographic projection but the linear distance corresponding to a degree of arc naturally increases from the center of the projection toward its circumference. This is illustrated in Fig. 61 where the circle represents a vertical section through the spherical projection and the line *A–B* represents the trace of the horizontal plane of the stereographic projection. A point 20° from *N* on the sphere is projected to the point *a* on the stereographic projection, a point 45° from *N* is projected to *b*, etc. In this way a protractor can be made by means of which angular distances from the center of the stereographic projection can be readily determined. Fig. 62 represents such a protractor which was devised by Penfield.† The mathematical relation between the linear distance from the center of the projection and its angular value is seen by study of Fig. 61. If the radius of the circle of the projection is taken as unity the distance from its center to any desired point is equal to the tangent of one half of the angle represented. For instance the distance

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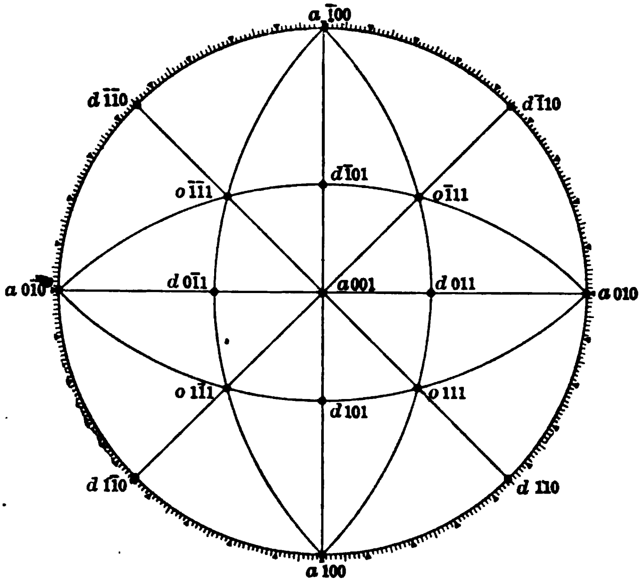
* For proof of this statement see Penfield, Am. Jour. Sci., 11, 10, 1901.

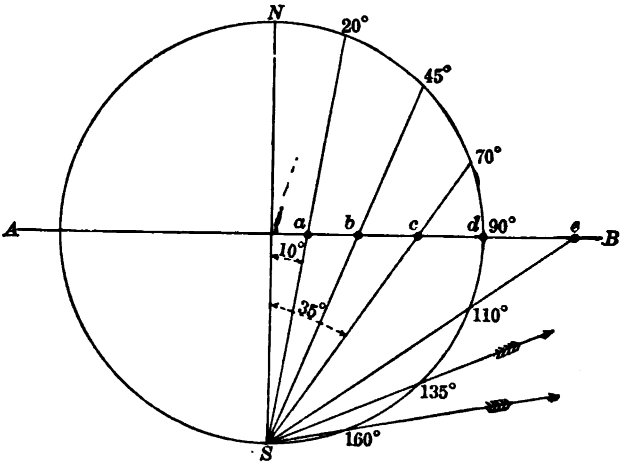
† This protractor and the other protractors and scales used by Penfield can be obtained from the Mineralogical Laboratory of the Sheffield Scientific School of Yale University, New Haven, Ct.

60



Stereographic Projection of the Isometric Forms, Cube, Octahedron, and Dodecahedron

61

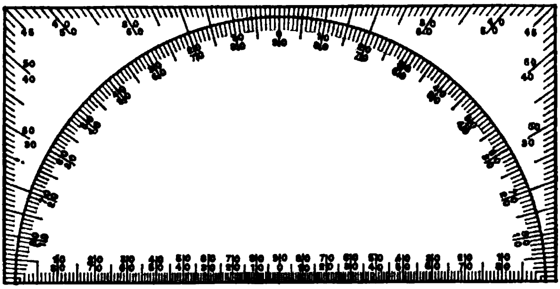


from the center to the point *a* is equivalent to the tangent of 10°, to point *c* the tangent of 35°, etc.

Fig. 63 represents a chart used by Penfield for making stereographic projections. The circle has a diameter of 14 cm. and is graduated to degrees. With it go certain scales that are very useful in locating the desired points and zonal circles. These will be briefly described later.

For detailed descriptions of the principles of the stereographic projection and the methods of its use the reader is referred to the various books and articles, the titles of which are given beyond. It is possible here to give only a brief outline of the more important methods of construction used.

62



Stereographic Protractor for plotting Stereographic Projections (after Penfield; reduced one-half)

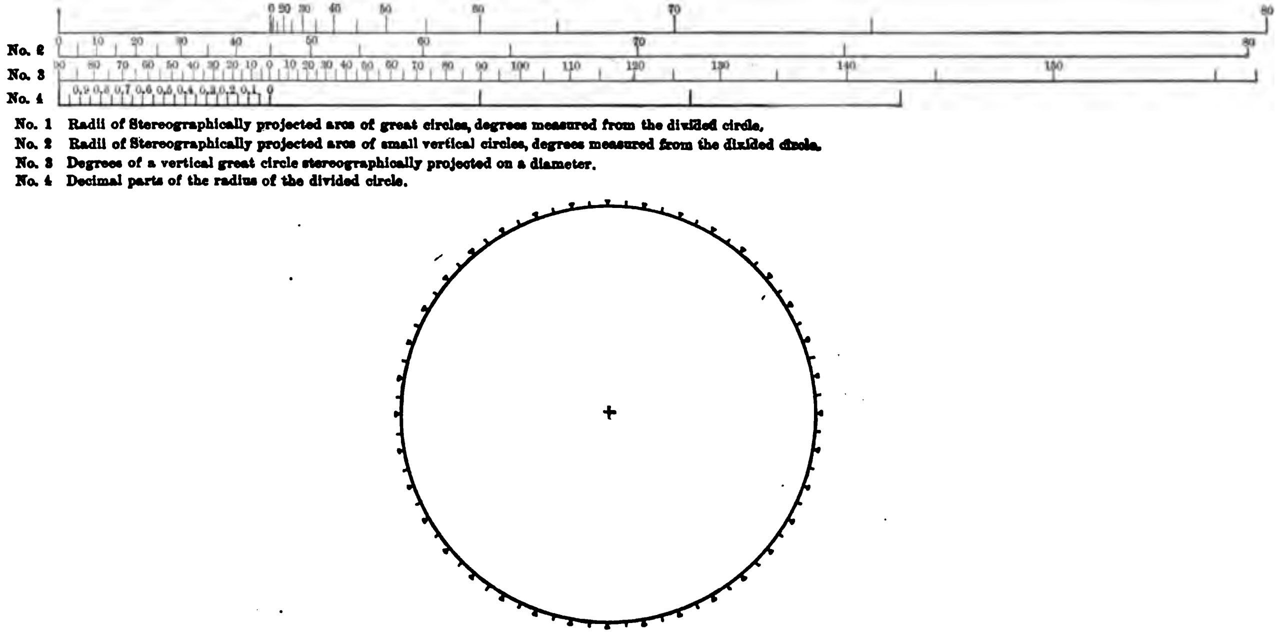
(1). *To locate the pole of a face lying on a known north and south great circle, its angular distance from the center or a point on the circumference of the projection being given.* The stereographic protractor, Fig. 62, or the tangent relation as stated above, gives the proper distance. The poles labeled *o* (isometric octahedron), Fig. 60, may be located in this way.

(2) *To locate the projection of the arc of a great circle which is not a north and south meridian or the equator.* The projections of three points on the arc must be known. Then, since the projection of the circle will be still a circular arc, its position can be determined by the usual geometric construction for a circle with three points on its arc given. If, as is commonly the case, the points where the great circle crosses the equator and the angle it makes with the equator are known it is possible to get the radius of the projected arc directly from Scale No. 1, Fig. 63. The location of such a desired arc is shown in Fig. 64. The arcs shown in Fig. 60 were also located in this way.

(3) *To locate the position of the pole of a face lying on a known great circle, which is not a north and south meridian, its angle from a point on the circumference of the projection being known.* The projected arc of a small vertical circle, whose radius is the known angle, is drawn about the point on the circumference of the projection and since all points on this arc must have the required angular distance from the given point the intersection of this circle with the known great circle will give the desired point. The radius of the projected arc of the small vertical circle can be determined by finding the position of three points on the projection which have the required angular distance from the point given on the circumference of the projection and then obtaining the center of the required circle in the usual way. Or by the use of Scale No. 2, Fig. 63, the required radius is obtained directly. It is to be noted that the known point on the circumference of the projection, while the stereographic center of the small circle, is not the actual center of the projected arc. The center will lie outside the circumference on a continuation of the radial line that joins the given point with the center of the projection. Therefore, even if the radius of the required arc is taken from

63

Penfield's Divided Circle and Scales for plotting Stereographic Projections.

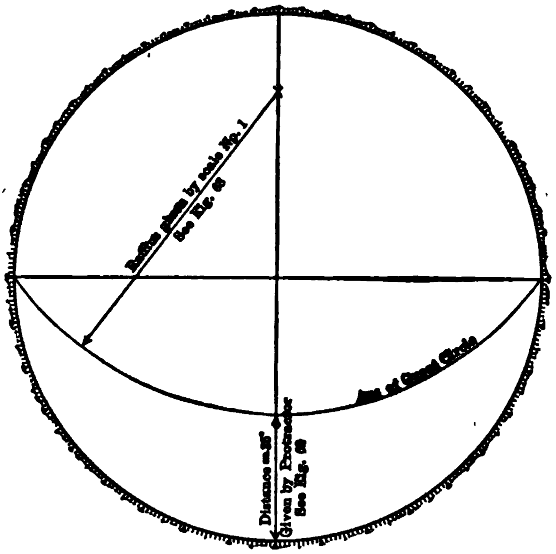


No. 1 Radii of Stereographically projected arcs of great circles, degrees measured from the divided circle.
No. 2 Radii of Stereographically projected arcs of small vertical circles, degrees measured from the divided circle.
No. 3 Degrees of a vertical great circle stereographically projected on a diameter.
No. 4 Decimal parts of the radius of the divided circle.

On the original engine-divided plate the circle has a diameter of 14 cm. and is divided into degrees. The scales likewise are subdivided so as to give desired parts to degrees

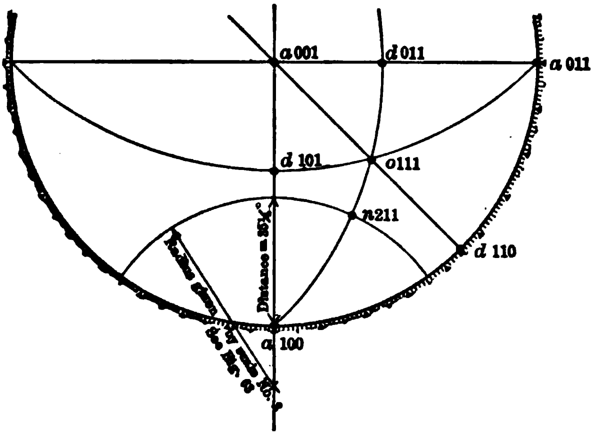
Scale No. 2, it will be necessary to establish at least one point on the required circle in order to find its center. These methods of construction are illustrated in Fig. 65, in which the position is determined of the pole *n* (isometric trapezohedron) which lies on the great circle passing through the poles *a* (isometric cube) and *o* (isometric octahedron), and makes a known angle ($35\frac{1}{4}°$) with *a*.

64



Location of the arc of a great circle in the Stereographic Projection at a given angle above the equator

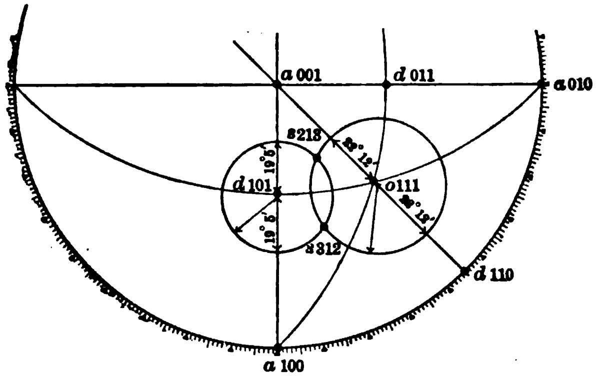
65



Location of pole of trapezohedron, *n*(211), in Stereographic Projection

(4) *To locate the position of the pole of a face given the angles between it and two other faces whose poles lie within the divided circle.* Circumscribe about the poles of the two known points small circles with the proper radii and the desired point will be located at their intersection. The two small circles may touch at only a single point or they may intersect in two points. In the latter case both points will meet the required conditions. The positions of the projected small circles are readily found by drawing radii from the center of the projection through the two known poles and then laying off on these radii points on either side of the known poles with the required angular distances. The center is then found between these two points in each case and a circle drawn through them. This line of this circle will then be everywhere the required number of degrees away from the known pole. The required points may be found readily by means of the Stereographic Protractor, Fig. 62, remembering that the zero point on the protractor must always lie at the center of the projection. This construction is illustrated in Fig. 66, in which the points *s* (isometric hexoctahedron), are 22° 12′ and 19° 5′ from the points *o* (isometric octahedron), and *d* (isometric dodecahedron). It is to be noted here, also, that while the points *o* and *d* are the stereographic centers of the circles about them, the actual centers are points which are somewhat farther out from the center of the projection.

66

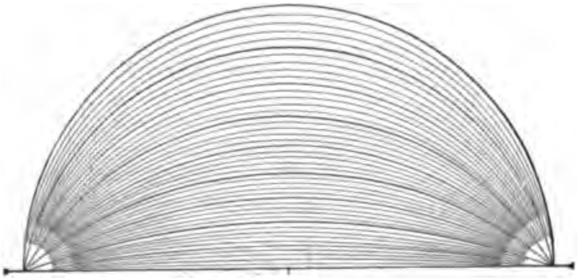


Location of two poles of hexoctahedron, *s*, in Stereographic Projection

(5) *To measure the angle between two given points on the stereographic projection.* If the two points lie on the circumference of the projection the angle between them is read directly from the divisions of the circle. If they lie on the same radial line in the projection, the angle is given by the use of the Stereographic Protractor, Fig. 62. In other cases it is necessary first to find the arc of a great circle upon which the two points lie. This is most easily accomplished by the use of a transparent celluloid protractor upon which the arcs of great circles are given, Fig. 67. Place this protractor over the projection with its center coinciding with the center of the projection and turn it about until the required great circle is found. Note the points where this circle intersects the circumference of the projection. Then place a second transparent protractor on which small vertical circles are given, Fig. 68, over the projection with its ends on the points of the circumference

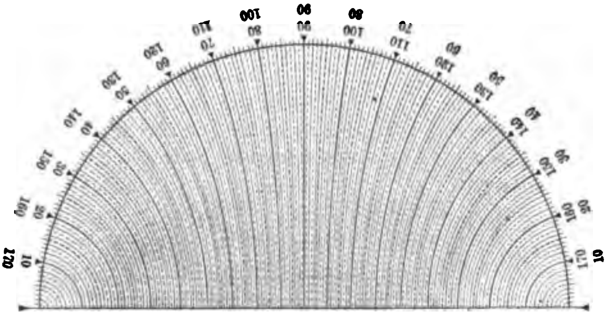
just determined. Now note the angular distance between the two given points. The whole operation may also be done by use of a third transparent protractor, on which the arcs of both great and small circles are given.

67



Stereographic Protractor, giving the great circles of every alternate degree (second, fourth, etc.) (After Penfield, reduced one-half)

68

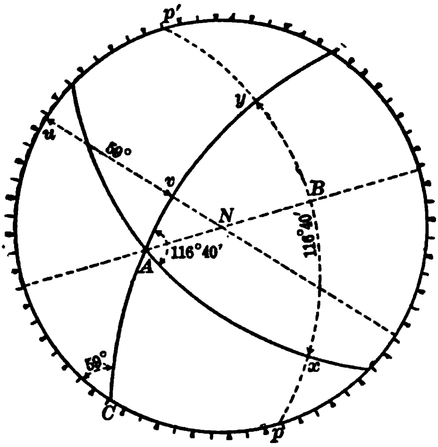


Stereographic Protractor, giving small circles for every degree measured from a given point on the circumference. (After Penfield, reduced one-half)

(6) *To measure the angle between the arcs of two great circles on the stereographic projection.* This is most conveniently accomplished by constructing the arc of a great circle which shall have a 90° radius about the point at which the two arcs in question cross each other and then measuring the angular distance between the two points at which they intersect this great circle. Fig. 69, after Penfield, will serve to illustrate the method. First, if it is wished to measure the angle between the divided circle and the arc of the great circle that crosses it at C it is only necessary to draw a straight line through the center of the projection, N, which shall intersect the divided circle at points 90° distant from C. This line will be the projection of the arc of a great circle about the sphere at 90° distant from C. The angle at C is then determined by measuring with the stereographic protractor the angle between u and v.

In the case of the angle between two great circles that meet at some point within the divided circle as at A, Fig. 69, it is necessary to construct the projected arc of the great circle 90° distant from this point This is done by drawing the radial line through *N* and *A* and measuring with the stereographic protractor an angle of 90° from *A* to the point *B*. The required arc will pass through this point and the points *p* and *p′* which are each 90° away from the points at which the line *A–N–B* crosses the divided circle. The angle between *x* and *y* measured on this great circle gives the value of the required angle at *A*. This is most readily measured by the use of the transparent protractor showing small circles, Fig. 68. This is placed across the projection from *p* to *p′* and the angle between *x* and *y* read directly from it.

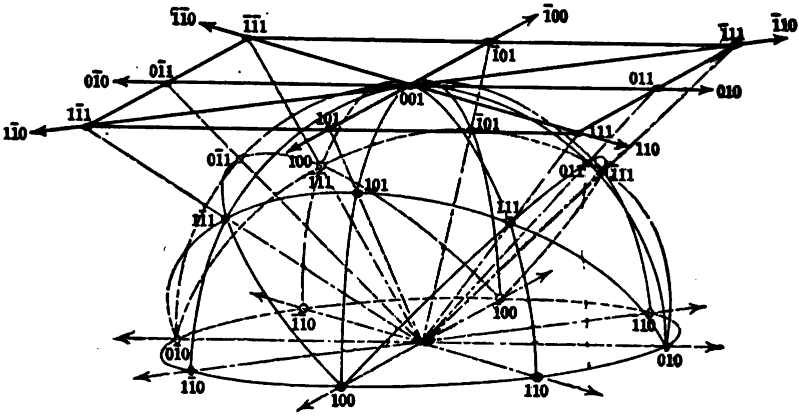
69



Wülfing has described a stereographic net, which gives both great and small circles for every two degrees. Over this is placed a sheet of tracing paper upon which the stereographic projection is made. If the paper is fastened at the center of the drawing so that it can be turned into various positions in respect to the stereographic net below, the various great and small circles needed can be sketched directly upon the drawing. Or the required points can be transferred from the net to a separate drawing by means of three point dividers.

Examples of the use of the stereographic projection will be given later under each crystal system.

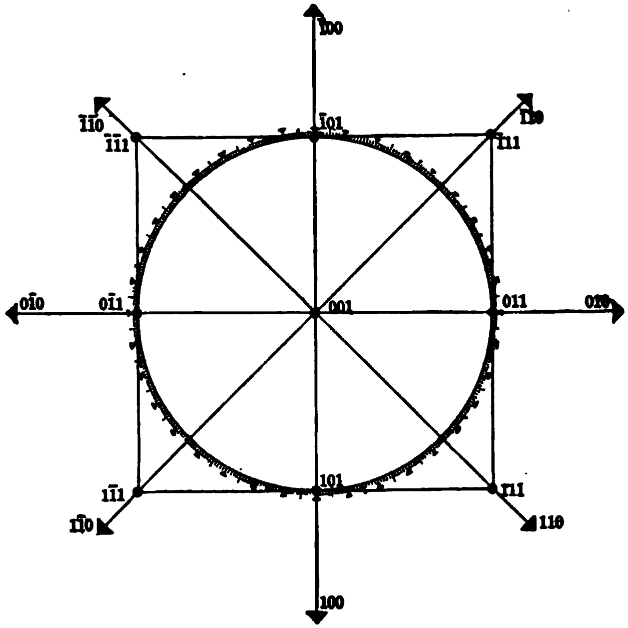
70



Relation between Spherical and Gnomonic Projections

42. The Gnomonic Projection. — The characters of the gnomonic projection can best be understood by considering it to be derived from the spherical projection (see Art. **40**). In the case of the gnomonic projection the plane of the projection is usually taken as the horizontal plane which lies tangent to the north pole of the sphere of the spherical projection. Imaginary lines are then taken from the center of the sphere through the poles of the crystal faces that lie on its surface and extended until they touch the plane of the projection. The points in which these lines touch that plane constitute the gnomonic projection of the forms represented. Fig. 70 shows the relations between the spherical and gnomonic projections, using the same isometric crystal forms (cube, octahedron and dodecahedron) as were employed to illustrate the principles of the Stereographic Projection (Art. **41**). Fig. 71 shows the gnomonic projection of the same set of forms.

71

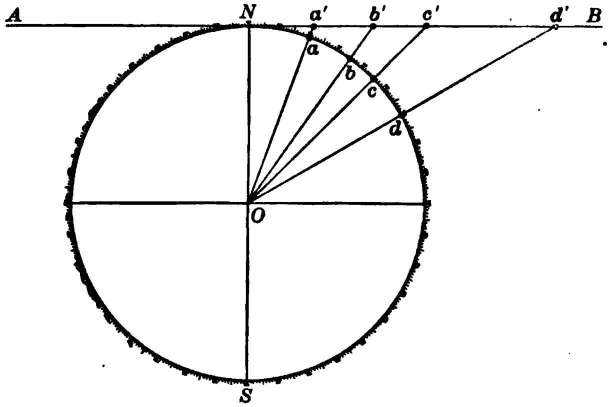


Gnomonic Projection of Cube, Octahedron and Dodecahedron

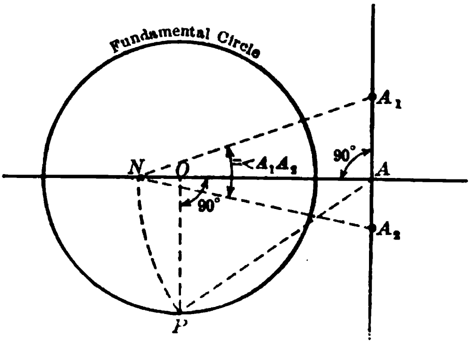
The following features of the gnomonic projection are important. All great circles on the spherical projection become straight lines when transferred to the gnomonic. The poles of a series of crystal faces which belong in the same zone will, therefore, on the gnomonic projection, lie on a straight line. This primary distinction between the stereographic and gnomonic projections will be readily seen by a comparison of Figs. 60 and 71. The pole of a horizontal crystal face (like the top face of the cube) will fall at the center of the projection. The poles of vertical crystal faces will lie on the plane of projection only at infinite distances from the center. This is shown by a consideration of Fig. 70. Such faces are commonly indicated on the projection by the use of radial lines or arrows which indicate the directions in which their poles lie. This is illustrated in the case of the vertical cube and dodecahedron faces in Fig. 71. Crystal faces having a steep inclination with the horizontal plane must frequently be indicated in the same way.

A simple relation exists between the linear distance from the center of the projection to a given point and the angular distance represented. This is shown in Fig. 72 where the circle is assumed to be a vertical cross-section of the sphere of the spherical projection and the line $A-B$ represents the trace of the plane of the gnomonic projection. It is evident from this figure that if the radius of the circle is taken as unity the linear distances $N-a'$, $N-b'$, etc., are the tangents of the angles 20°, 35°, etc. Consequently in the gnomonic projection the distance of a given pole from the center of the projection, considering the fundamental distance $O-N$, Fig. 72, to be unity, is equal to the tangent of the angle represented. In the case of the stereographic projection this distance is equal to the tangent of one half the angle, see Art. **41.** The stereographic scale, used in the stereographic protractor, Fig. 62, can therefore be adapted for use in the gnomonic projection by taking the point on it reading at twice the desired angle. The simplest method of plotting, however, is to make a direct use of the tangent relation. The distance $O-N$, Fig. 72, is taken at some convenient length and then by multiplying this distance by the natural tangent of the angle desired the linear distance of the pole in question from the center of the projection is obtained. Frequently the distance $O-N$ is taken as 5 cm. In making a gnomonic projection a circle is commonly drawn about the center of the projection, known as the fundamental circle, with a radius equal to this chosen distance. Points that have an angular distance of 45° with the center point of the projection will lie on the circumference of this circle. Commonly also the gnomonic projection is surrounded by a square border of two parallel lines on which is indicated the directions in which lie the poles that cannot appear on the projection because of the vertical or steeply inclined position of their faces. These characters are shown in Fig. 71.

72



73



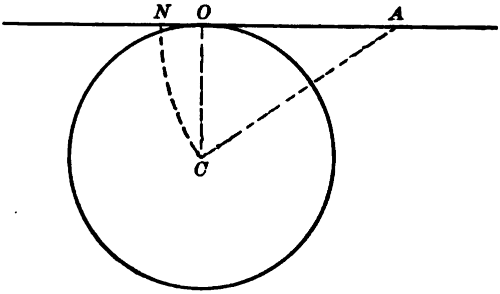
Measurement of angle between any two poles (A_1, A_2) on the Gnomonic Projection

To measure the angle between two poles on the gnomonic projection. In

Fig. 73 let A_1 and A_2 be any two points the angle between which is desired. First draw a straight line through them or, in other words, find the direction of the zonal line upon which they lie. Next erect the line O–A perpendicular to this zonal line and passing through the center O of the projection. On this line establish the point N, the distance A–N being equal to the hypothenuse of the right triangle AOP or the distance A–P. The point N is known as the *angle-point* of the zone A_1–A_2. The angle A_1NA_2 is equal to the desired angle between the points A_1 and A_2. In the case of zonal lines that pass through the center of the projection this angle-point will lie on the circumference of the fundamental circle at the terminus of a radius which is at right angles to the zonal line in question. In the case of vertical crystal faces whose poles lie at an infinite distance the center of the projection is itself the angle-point.

The explanation of the above method may be given as follows. In Fig. 74 let the circle represent a vertical section through the sphere of the spherical projection and the line N-A the trace of the plane of the gnomonic projection. Let the line A–C represent the intersection of a zonal plane lying at right angles to the plane of the drawing. The zonal line representing the intersection of this zonal plane with the plane of the gnomonic projection would therefore be a straight line through point A which would be perpendicular to the plane of the drawing. The angle between any two poles lying on this zonal line would be determined by the angle formed by the lines drawn from these poles to the point C. If we consider this zonal line which passes through A perpendicular to the drawing as an axis around which we may revolve its zonal plane, the point C may be moved so that it will lie in the plane of the gnomonic projection and fall at N, the distance A–N being equal to A–C. The character of the point C has not been changed by this transfer and the point N becomes the angle-point of the zonal line running through A and the angle between any two poles on this line may be determined by running lines from them to this point and measuring the included angle. The point N lies on the line running through O (center of the gnomonic projection) and the distance A–N is equal to the hypothenuse, A–C, of the right triangle one side of which is equal to A–O and the other to O–C (the radius of the fundamental circle).

74

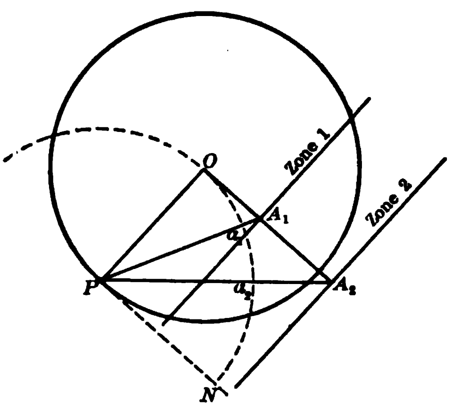


To measure the angle between parallel zonal lines on the gnomonic projection. In Fig. 75 let the two lines Zone 1 and Zone 2 represent two parallel zonal lines the angle between which is desired. Draw the radial line from the center of the projection, O, at right angles to these zonal lines intersecting them at the points A_1 and A_2. Make O–P at right angles to O–A_1A_2. The angle A_1PA_2 will give the angle between the two zones. The construction will be readily understood if the figure is supposed to be turned on the line O–A_1A_2 as on an axis until the point P becomes the center of the spherical projection The broken arc now represents a vertical cross section of the sphere of the spherical projection and the points a_1 and a_2 the points where the two zonal lines cross it. The angle at P is obviously the angle between the two zones.

The angle between Zone 2 and the prism zone, the line of which lies at infinity on the gnomonic projection, is given in Fig. 75 by the angle A_2PN which is the same as A_1A_2P.

A gnomonic net, similar in character to the stereographic net described in Art. **41**, is useful in plotting the points of a projection or in making measurements upon it. The straight lines upon it represent the projection of the arcs of great circles of the spherical projection, while the hyperbola curves represent those of the small vertical circles.

75



Measurement of the angle between parallel zones on the Gnomonic Projection

The gnomonic projection is most commonly used in connection with the measurement of crystal angles by means of the two-circle goniometer. This use will be explained later, see Art. **232**. For more detailed descriptions of the principles and uses of the gnomonic projection the reader is referred to the literature listed below.

References on the Stereographic and Gnomonic Projections.

In addition to the descriptions of these projections that are given in many general crystallographic texts the following books and papers are of value.

Boecke, H. E. Die Anwendung der stereographischen Projektion bei kristallographischen Untersuchungen, 1911. Die gnomonische Projektion in ihrer Anwendung auf kristallographische Aufgaben, 1913.

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Goldschmidt, V. Über Projektion und graphische Kristallberechnung, 1887.

Gossner, B. Kristallberechnung und Kristallzeichnung, 1914.

Hilton, H. The Gnomonic Net, Min. Mag., **14**, 18–20, 1904. The Construction of Crystallographic Projections, Min. Mag., **14**, 99–103, 1905. Some Applications of the Gnomonic Projection to Crystallography, Min. Mag., **14**, 104–108, 1905.

Hutchinson, A. On a protractor for use in constructing stereographic and gnomonic projections of the sphere, Min. Mag., **15**, 94–112, 1908.

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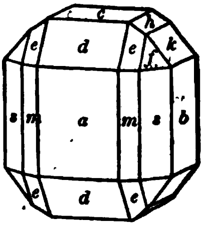
Penfield, S. L. The Stereographic Projection and Its Possibilities from a Graphical Standpoint, Am. J. Sci., **9**, 1–24, 115–144, 1901. On the Solution of Problems in Crystallography by Means of Graphical Methods based upon Spherical and Plane Trigonometry. Am. J. Sci., **14**, 249–284, 1902. On the Drawing of Crystals from Stereographic and Gnomonic Projections, Am. J. Sci., **21**, 206–215, 1906.

Smith, G. H. H. On the Advantages of the Gnomonic Projection and its use in the Drawing of Crystals, Min. Mag., **13**, 309–321, 1903.

76



Chrysolite

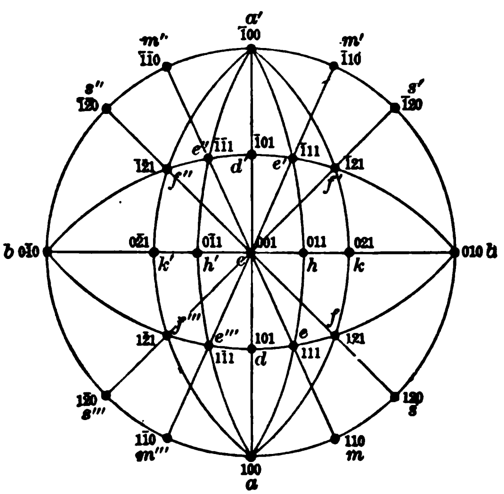
43. Angles between Faces. — The angles most conveniently used with the Miller symbols, and those given in this work, are the *normal angles*, that is, the angles between the poles or normals to the faces, measured on arcs of great circles joining the poles as shown on the stereo graphic projection. These normal angles are the supplements of the actual interfacial angles, as has been explained.

The relations between these normal angles, for example in a given zone, is much simpler than those existing between the actual interfacial angles. Thus it is always true that, for a series of faces in the same zone, the normal angle between two end faces is equal to the sum of the angles of faces falling between. Thus (Figs. 76, 77) the normal angle of *ab*(100 ∧ 010) is the sum of *am*(100 ∧ 110), *ms*(110 ∧ 120), and *sb*(120 ∧ 010). This relation holds true in all the systems.

Furthermore, it will be seen that, supposing *aca'* (Fig. 77) is a plane of symmetry as in the orthorhombic system, the angle 100 ∧ 110, or *am* (Fig. 76), is half the angle 110 ∧ $1\bar{1}0$(*mm'''*). Similarly 010 ∧ 120(*bs*) is half the angle 120 ∧ $\bar{1}20$(*ss'*); again, 100 ∧ 111(*ae*) is the complement of half the angle 111 ∧ $\bar{1}11$(*ee'*) and 010 ∧ 111(*be*) the complement of half the angle 111 ∧ $1\bar{1}1$(*ee'''*).

Here, as throughout this work, the sign ∧ is used to represent the angle between two faces, usually designated by letters.

77



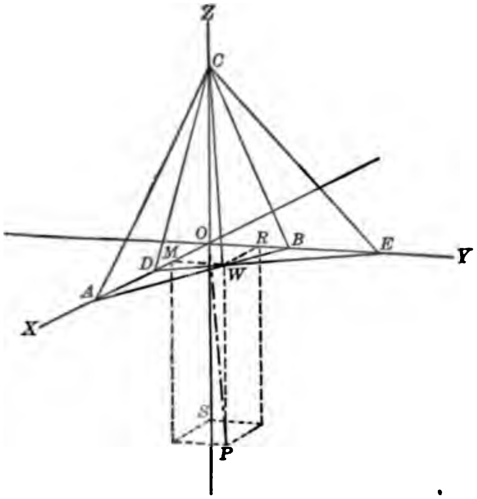
Stereographic Projection of Faces on Chrysolite Crystal, Fig. 76

44. Use of the Stereographic Projection to Exhibit the Symmetry.

— The symmetry of any one of the crystalline classes may be readily exhibited by the help of the stereographic projection.

The axes of binary, trigonal, tetragonal and hexagonal symmetry are represented respectively by the following signs: ⬬ ▲ ◆ ⬢. Further, a plane of symmetry is represented by a full line (zone-circle), while a dotted line indicates that the plane of symmetry is wanting. The position of the crystallographic axes is shown by arrows at the extremities of the lines. The pole of a face in the upper half of the crystal (above the plane of projection) is represented by a cross; one below by a circle. If two like faces fall in a vertical zone a double sign is used, a cross within the circle. Figs. 91, 128, 140, etc., give illustrations.

78

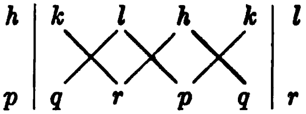


45. General Relations between Planes in the Same Zone.

— Certain important relations exist between the indices of faces that lie in the same zone. All faces to belong to the same zone, *tautozonal faces* as they are called, must have their mutual intersections parallel to a given direction, see Art. **38.** This direction is known as the axis of the zone. The position of this zonal axis can be expressed by what is known as the zonal symbol. Consider Fig. 78, where is represented two crystal faces, *ABC*, and *CDE*, intersecting the crystallographic axes *X*, *Y* and *Z*. In the illustration, for simplicity, both faces have been assumed to pass through the point C on the axis Z. This, of course, is possible since any crystal plane may be moved parallel to itself without altering its relative intercepts on the crystal axes. These two planes intersect in the line $C{-}W$, which then becomes the direction of the zonal axis for the zone in which they lie. Let the line $O{-}P$ which has been drawn parallel to this direction represent that axis. In the parallelogram of which it is the diagonal the length of the edge $O{-}S$ and its parallel edges have been taken as equal to the distance $O{-}C$. The point P on the zonal axis and therefore the direction of the axis itself is fixed by the three coördinates, $O{-}M$, $O{-}R$, and $O{-}S$. By means of the consideration of similar triangles it is possible to prove that the values of these coördinates may be expressed by,

$$O{-}M = (kr - lq)a;\ O{-}R = (lp - hr)b;\ O{-}S = (hq - kp)c,$$

where a, b, c represent the unit lengths of the three crystallographic axes, X, Y, Z and (hkl) and (pqr) represent the indices of the two faces ABC and CDE. These expressions are usually simplified by substituting $u = kr - lq$, $v = lp - hr$, $w = hq - kp$, giving $O{-}M = ua$, $O{-}R = vb$ and $O{-}S = wc$. The three figures $[uvw]$ are said to be the symbol of the zone in question. They represent the reciprocals of the values of the three coördinates, or in other words are the indices of a point, P, on the zonal axis. They may most readily be obtained by a system of cross-multiplication and subtraction according to the following scheme. Write the indices of one face twice in their proper order and directly under them the corresponding indices of the second face. Cross off the first and last number of each series. Then multiply the figures joined by the cross lines, see below, and substract the product of the two joined by light lines from that of those joined by heavy lines, working from left to right. The three numbers obtained will in their order correspond to u, v and w.



$$u = kr - lq,\ v = lp - hr,\ w = hq - kp.$$

Since the zonal symbol for a given zone may be obtained from the indices of any two faces lying in that zone it follows that the indices of every possible face in that zone must have definite relations to the zonal symbol. For a given face with indices (xyz), in a zone having the symbol $[uvw]$ the following equation, known as the zonal equation, must hold true.

$$ux + vy + wz = 0.$$

In this way it can be readily shown whether or not a given face can lie in a certain zone.

Further if $[uvw]$ be the symbol of one zone and $[efg]$ that of another intersecting it, then the point of intersection will always be the pole of a possible crystal face. Its indices (hkl) must satisfy the equations of both zones and may be obtained by combining them or the same result may be had by taking the symbols of the two zones and subjecting them to the same sort of cross-multiplication by which they were themselves originally derived.

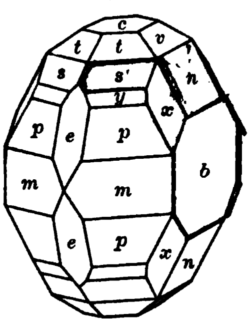
46. — Examples of Zones and Zonal Relations. — The following are cases in which the zonal equation is seen at once. In Figs. 76 and 77 the faces *a*(100), *m*(110), *s*(120), *b*(010) form a vertical zone with mutually parallel intersections, since they are all parallel to the vertical axis; that is, for all faces in this zone it must be true that $l = 0$.

Again, the faces *a*(100), *d*(101), *c*(001) are in a zone, all being parallel to the horizontal axis *b*; hence for them and all others in this zone $k = 0$. Also *b*(010), *k*(021), *h*(011), *c*(001) are in a zone, all being parallel to the axis *a*, so that $h = 0$.

Also the faces *f*(121), *e*(111), *d*(101), $e''(1\bar{1}1)$, $f'''(1\bar{2}1)$ are in a zone, since they have a common ratio for the axes $a : c$. With them, obviously, $h = l$.

The faces *c*(001), *e*(111), *m*(110) are also in a zone, and again *c*(001), *f*(121), *s*(120), though intersections do not happen to be made between *c* and *e* in the one case, and *c* and *f* in the other. For each of these zones it is true that there is a common ratio of the horizontal axes, that is, of *h* to *k* in the indices. For the first it may be shown that $h = k$; for the second, that $2h = k$.

79



Sulphur

All the relations named may be obtained at once from the above scheme. For example, for the faces *s*(120) and *f*(121) the scheme gives

$$\begin{array}{c|cccc|c} 1 & 2 & 0 & 1 & 2 & 0 \\ 1 & 2 & 1 & 1 & 2 & 1 \end{array}$$

u = 2, v = $\bar{1}$, w = 0; $\therefore 2h - k = 0$, or $2h = k$.

The symbol of a face lying at once in two zones, as stated above, must satisfy the zonal equation of each; these symbols are hence easily obtained either by combining the equations or by a scheme of multiplication like that given above.

For example, in Fig. 79, of sulphur, the face lettered *x* is in the zone (1) with *b*(010) and *s*(113), also in zone (2) with *p*(111) and *n*(011). These zones give, respectively:

$$(1)\quad \begin{array}{c|cccc|c} 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 3 & 1 & 1 & 3 \\ \hline & 3 & 0 & \bar{1} & & \end{array} \qquad (2)\quad \begin{array}{c|cccc|c} 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 & 1 & 1 \\ \hline & 0 & \bar{1} & 1 & & \end{array}$$

u = 3, v = 0, w = $\bar{1}$. *e* = 0, *f* = $\bar{1}$, *g* = 1.

Hence for (1) the zonal equation is $3h = l$; for (2) $k = l$. Combining these, we obtain $h = 1$, $k = 3$, $l = 3$.

The symbol of the face *x* is, therefore, 133.

The same result is given by multiplying the zonal symbols $0\bar{1}1$, $30\bar{1}$, together after the same method, thus:

$$\begin{array}{c|cccc|c} 0 & \bar{1} & 1 & 0 & \bar{1} & 1 \\ \bar{3} & 0 & 1 & \bar{3} & 0 & 1 \\ \hline & 1 & 3 & 3 & & \end{array}$$

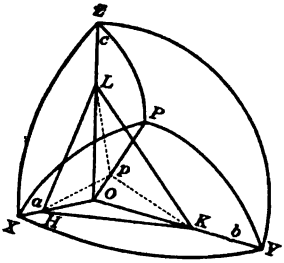
Hence, again, $x = 133$.

This method of calculation belongs to all the different systems. In the hexagonal system, in which there are four indices, one of the three referring to the horizontal axes (usually the third) is omitted when the zonal relations are applied. See Art. **166**.

47. Methods of Calculation. — In general the angles between the poles can be calculated by the methods of spherical trigonometry from the triangles shown in the spherical projection — which for the most part are right-angled. Certain fundamental relations connect the axes with the elemental angles of the projection; the most important of these are given under the individual systems. Some general relations only are explained here.

48. Relations between the Indices of a Plane and the Angle made by it with the Axes. — In Fig. 80 let the three lines, X, Y, and Z represent three crystallographic axes making any angles with each other and let a, b and c represent their unit lengths. Assume any face HKL cutting these axes with the intercepts $O\text{-}H$, $O\text{-}K$ and $O\text{-}L$. Let $O\text{-}p\text{-}P$ be a normal to the plane HKL intersecting the plane at p and the enveloping surface of the spherical projection at P. Let hkl represent the indices of the given form. Since the line $O\text{-}p$ is normal to the plane HKL the triangles HOp, KOp and LOp are right angles and the following relations hold true.

80



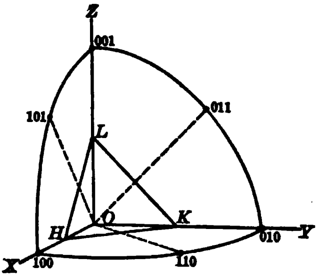
$$\frac{Op}{OH} = \cos HOp; \quad \frac{Op}{OK} = \cos KOp; \quad \frac{Op}{OL} = \cos LOp.$$

The angles HOp, KOp, and LOp are equal, respectively, to the angles represented on the spherical projection by the arcs PX, PY and PZ and $OH = \frac{a}{h}$, $OK = \frac{b}{k}$, $OL = \frac{c}{l}$. By substituting we have,

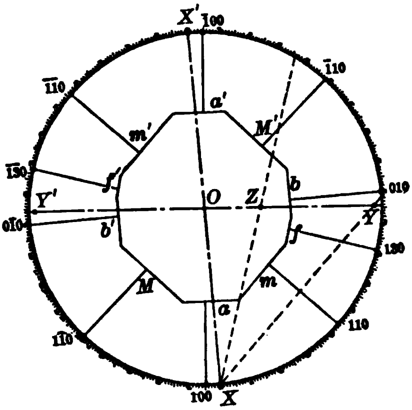
$$OP = \frac{a}{h}\cos PX = \frac{b}{h}\cos PY = \frac{c}{l}\cos PZ.$$

This equation is fundamental, and several of the relations given beyond are deduced from it.

81



82



The most useful application is that when the axial angles are 90°, as represented in Fig. 81; then X, Y, Z are the normals to 100, 010, 001, respectively. Also if the plane HKL is taken as a face of the unit pyramid, that is, if its intercepts on the axes are taken as the unit lengths

$$OH = a, \qquad OK = b, \qquad OL = c.$$

Then the lines HK, HL, KL give also the intersections of the planes 110, 101, 011 on the three axial planes, and their poles are hence at the points fixed by normals to these lines drawn from O. It will be obvious from this figure, then, that the following relations hold true:

$$\tan (100 \wedge 110) = \frac{a}{b};$$

$$\tan (001 \wedge 101) = \frac{c}{a};$$

$$\tan (001 \wedge 011) = \frac{c}{b}.$$

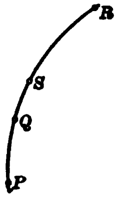
These values are often used later.

49. Cotangent and Tangent Relations. — In the case of four faces in a zone concerning which we know, either the angles between all the faces and the indices of three of them, or the angles between three faces and all the indices, it is possible by either a simple graphical method of plotting or by calculation to determine the missing angle or indices.

To illustrate the graphic method first let Fig. 82 represent a cross section perpendicular to the prism zone of a rhodonite crystal. The traces upon the plane of the drawing of the faces *a*(100) and *b*(010) provide the direction of the lines of reference X and Y. It is assumed that the position of the third face *m*(110) is known and a line drawn parallel to its trace upon the plane of the drawing from the point X will give its relative intercepts upon the two lines of reference. These intercepts do not correspond to the unit lengths of the axes *a* and *b* since, rhodonite being triclinic, these axes do not lie in the plane of the drawing but they represent rather the unit lengths of these axes as foreshortened by projection upon that plane. This makes no difference, however, since it will still be true that all faces lying in the prism zone of rhodonite must intercept these two lines in distances which will have rational relations to the lengths of the intercepts of *m*(110). It is now assumed that a fourth face *f* has the indices (130) and its angular position in respect to the other faces in the zone is required. From its indices it must intercept the two lines of reference X–X′ and Y–Y′ in the ratio of 1 to $\frac{1}{3}$. Let OX equal 1 on X–X′ and OZ equal $\frac{1}{3}$ on Y–Y′. Then a line joining these two points will give the direction of the trace of *f* upon the plane of the drawing and so determine the angles it will make with the other faces in the zone.

If, on the other hand, the angles between *f* and the other faces in the zone were known, the position of the trace of *f* upon the plane of the drawing could be found, and so its relative intercepts (and indices) upon the two lines of reference be determined.

83



If the method of calculation is used let P, Q, S and R be the poles of four faces in a zone (Fig. 83) taken in such an order * that PQ < PR and let the indices of these faces be respectively

P	Q	R	S
hkl	*pqr*	*uvw*	*xyz*

Then it may be proved that

$$\frac{\cot PS - \cot PR}{\cot PQ - \cot PR} = \frac{(P.Q)}{(Q.R)} \times \frac{(S.R)}{(P.S)}$$

---

* In the application of this principle it is essential that the planes should be taken in the proper order, as shown above; to accomplish this it is often necessary to use the indices and corresponding angles, not of (*hkl*), but the face opposite ($\bar{h}\,\bar{k}\,\bar{l}$), etc.

where

$$\begin{array}{cccccccc} & 123 & & 1\times 2 & & 2\times 3 & & 3\times 1\\ \dfrac{(P.Q)}{(Q.R)} & \left[\begin{array}{l} P,\ hkl\\ \underline{Q,\ pqr}\\ Q,\ pqr\\ R,\ uvw\end{array}\right] & = & \dfrac{hq-kp}{pv-qu} & = & \dfrac{kr-lq}{qw-rv} & = & \dfrac{lp-hr}{ru-pw}\end{array}$$

$$\begin{array}{cccccccc} & 123 & & 1\times 2 & & 2\times 3 & & 3\times 1\\ \dfrac{(S.R)}{(P.S)} & \left[\begin{array}{l} S,\ xyz\\ \underline{R,\ uvw}\\ P,\ hkl\\ S,\ xyz\end{array}\right] & = & \dfrac{xv-yu}{hy-kx} & = & \dfrac{yw-zv}{kz-ly} & = & \dfrac{zu-xw}{lx-hz}\end{array}$$

If one of these fractions reduces to an indeterminate form, $\frac{0}{0}$, then one of the others must be taken in its place.

This formula is chiefly used in the monoclinic and triclinic systems; and some special cases are referred to under these systems.

The cotangent relation becomes much simplified for a rectangular zone, that is, a zone between a pinacoid and a face lying in a zone at right angles to it so that the angle PR becomes 90°. In Fig. 83 let P(hkl) and Q(pqr) be two faces lying in the zone between a(100) and d(011) with the angle $a \wedge d = 90°$. Let Pa and Qa represent the angles between the two faces and the pinacoid a. Then the following holds true.

$$\frac{h}{p} \times \frac{\tan \mathrm{P}a}{\tan \mathrm{Q}a} = \frac{k}{q} = \frac{l}{r},$$

or the faces P and Q lie in zones with the other pinacoids b(010) or c(001) the expression becomes

$$\frac{h}{p} = \frac{k}{q} \times \frac{\tan \mathrm{P}b}{\tan \mathrm{Q}b} = \frac{l}{r},$$

$$\frac{h}{p} = \frac{k}{q} = \frac{l}{r} \times \frac{\tan \mathrm{P}c}{\tan \mathrm{Q}c}.$$

If the zone in question lies between two pinacoids which are at right angles to each other so that the indices of the faces P and Q become either $hk0$ and $pq0$, $h0l$ and $p0r$ or $0kl$ and $0qr$, we have

$$\frac{\tan\,(100 \wedge hk0)}{\tan\,(100 \wedge pq0)} = \frac{k}{h}\cdot\frac{p}{q};$$

$$\frac{\tan\,(001 \wedge h0l)}{\tan\,(001 \wedge p0r)} = \frac{h}{l}\cdot\frac{r}{p};$$

$$\frac{\tan\,(001 \wedge 0kl)}{\tan\,(001 \wedge 0qr)} = \frac{k}{l}\cdot\frac{r}{q}.$$

These equations are the ones ordinarily employed to determine the symbol of any prismatic plane or dome.

The most common and important application of this tangent principle is where the positions of the unit faces 110, 101, 011 are known, then the relation becomes

$$\frac{\tan\,(100 \wedge hk0)}{\tan\,(100 \wedge 110)} = \frac{k}{h}, \quad \text{or} \quad \frac{\tan\,(010 \wedge hk0)}{\tan\,(010 \wedge 110)} = \frac{h}{k}.$$

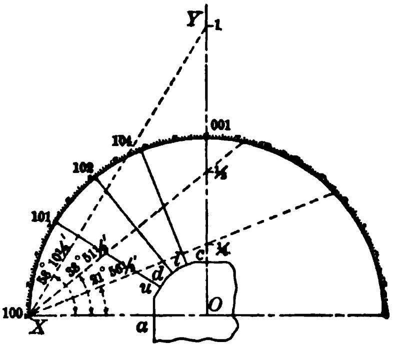
Also,

$$\frac{\tan\,(001 \wedge h0l)}{\tan\,(001 \wedge 101)} = \frac{h}{l}, \quad \frac{\tan\,(001 \wedge 0kl)}{\tan\,(001 \wedge 011)} = \frac{k}{l}$$

Thus the tangents of angles between the base, 001, and 102, 203, 302, 201, etc., are respectively ½, ⅔, $\frac{3}{2}$, 2 times the tangent of the angle between 001 and 101. Again, the tangent of the angle 100 ∧ 120 is twice the tangent of 100 ∧ 110 $\left(\text{here } \frac{k}{h} = 2\right)$, and one-half the tangent of 010 ∧ 110.

These last relations are shown clearly in Fig. 84 which represents a cross-section of a barite crystal showing the macrodome zone between $a(100)$ and $c(001)$. It is assumed that the angles between the faces a, u, d, l and c have been measured and the positions of their poles determined as indicated in the figure. The broken lines drawn from a point x on the line representing the a crystallographic axis show the direction of the traces of these faces upon the plane of the a and c axes. If the face u is assumed to be the unit dome (101) it will intersect the two axes at distances proportional to their unit lengths, namely O–X and O–Y. The other faces d and l are seen to intersect the c axis at ½ and ¼ the distance O–Y, giving them the indices (102) and (104). But the intercepts on O–Y for the three faces u, d and l are proportional to the tangents of the angles between their poles and that of $c(001)$ as shown below.

84



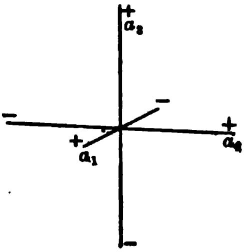
$$\begin{aligned}\tan 58^\circ\, 10\tfrac{1}{2}' &= 1.6112 = 1\\ \tan 38^\circ\, 51\tfrac{1}{2}' &= .8056 = \tfrac{1}{2}\\ \tan 21^\circ\, 56\tfrac{1}{2}' &= .4028 = \tfrac{1}{4}\end{aligned}$$

I. ISOMETRIC SYSTEM

(Regular or Cubic System)

50. The Isometric System embraces all the forms which are referred to three axes of equal lengths and at right angles to each other. Since these axes are mutually interchangeable it is customary to designate them all by the letter *a*. When properly orientated (*i.e.* placed in the commonly accepted position for study) one of these axes has a vertical position and of the two which lie in the horizontal plane, one is perpendicular and the other parallel to the observer. The order in which the axes are referred to in giving the relations of any face to them is indicated in Fig. 85 by lettering them a_1, a_2 and a_3. The positive and negative ends of each axis are also shown.

85



Isometric Axes

There are five classes here included; of these the normal class,* which possesses the highest degree of symmetry for the system and, indeed, for all crystals, is by far the most important. Two of the other classes, the pyritohedral and tetrahedral, also have numerous representatives among minerals.

1. NORMAL CLASS (1). GALENA TYPE

(Hexoctahedral or Holohedral Class)

51. Symmetry. — The symmetry of each of the types of solids enumerated in the following table, as belonging to this class, and of all their combinations, is as follows.

Axes of Symmetry. There are three principal axes of tetragonal symmetry which are coincident with the crystallographic axes and are sometimes known as the cubic axes since they are perpendicular to the faces of the cube. There are three diagonal axes of trigonal symmetry which emerge in the middle of the octants formed by the cubic axes. These are known as the octahedral axes since they are perpendicular to the faces of the octahedron. Lastly there are six diagonal axes of binary symmetry which bisect the plane angles made by the cubic axes. These are perpendicular to the faces of the dodecahedron and are known as the dodecahedral axes. These symmetry axes are shown in the Figs. 86–88.

Planes of Symmetry. There are three principal planes of symmetry which are at right angles to each other and whose intersections fix the position of the crystallographic axes, Fig. 89. In addition there are six diagonal planes of symmetry which bisect the angles between the principal planes, Fig. 90.

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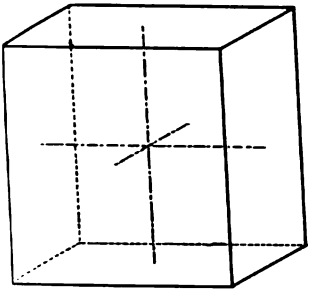
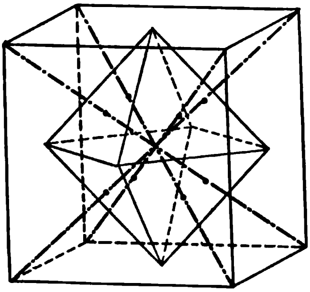
* It is called *normal*, as before stated, since it is the most common and hence by far the most important class under the system; also, more fundamentally, because the forms here included possess the highest grade of symmetry possible in the system. The cube is a possible form in each of the five classes of this system, but although these forms are alike geometrically, it is only the cube of the normal class that has the full symmetry as regards molecular structure which its geometrical shape suggests. If a crystal is said to belong to the isometric system, without further qualification; it is to be understood that it is included here. Similar remarks apply to the normal classes of the other systems.

86



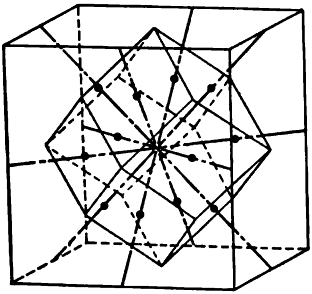
Axes of Tetragonal Symmetry
(Cubic Axes)

87



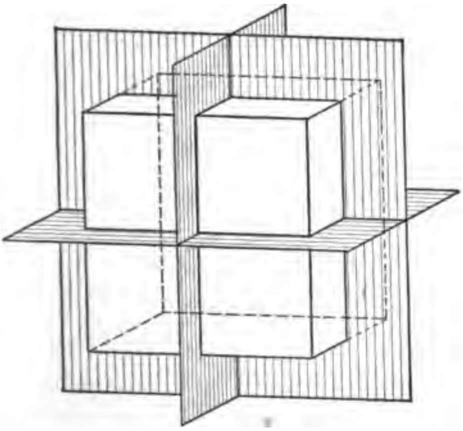
Axes of Trigonal Symmetry
(Octahedral Axes)

88



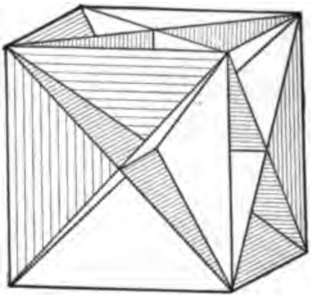
Axes of Binary Symmetry
(Dodecahedral Axes)

89



Principal Symmetry Planes

90

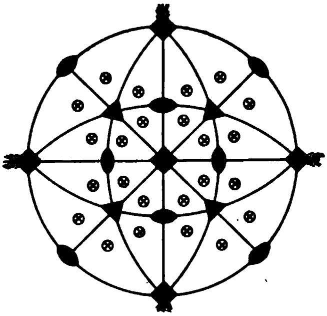


Diagonal Symmetry Planes

The accompanying stereographic projection (Fig. 91), constructed in accordance with the principles explained in Art. **44**, shows the distribution of the faces of the general form, *hkl* (hexoctahedron) and hence represents clearly the symmetry of the class. Compare also the projections given later.

52. Forms. — The various possible forms belonging to this class, and possessing the symmetry defined, may be grouped under seven types of solids. These are enumerated in the following table, commencing with the simplest.

91



Symmetry of Normal Class,
Isometric System

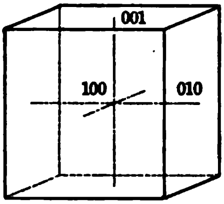
	Indices
1. Cube	(100)
2. Octahedron	(111)
3. Dodecahedron	(110)
4. Tetrahexahedron	(*hk*0) as, (310); (210); (320), etc.
5. Trisoctahedron	(*hhl*) as, (331); (221); (332), etc.
6. Trapezohedron	(*hll*) as, (311); (211); (322), etc.
7. Hexoctahedron	(*hkl*) as, (421); (321), etc.

Attention is called to the letters uniformly used in this work and in Dana's System of Mineralogy (1892) to designate certain of the isometric forms.* They are:

Cube: *a*.
Octahedron: *o*.
Dodecahedron: *d*.
Tetrahexahedrons: $e = 210$; $f = 310$; $g = 320$; $h = 410$.
Trisoctahedrons: $p = 221$; $q = 331$; $r = 332$; $\rho = 441$.
Trapezohedrons: $m = 311$; $n = 211$; $\beta = 322$.
Hexoctahedrons: $s = 321$; $t = 421$.

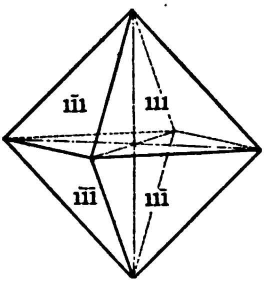
53. Cube. — The *cube*, whose general symbol is (100), is shown in Fig. 92. It is bounded by six similar faces, each parallel to two of the axes. Each face is a square, and the interfacial angles are all 90°. The faces of the cube are parallel to the principal or axial planes of symmetry.

92



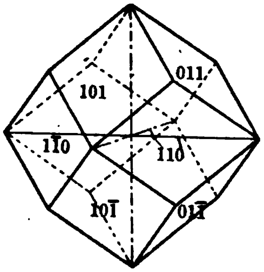
Cube

93



Octahedron

94



Dodecahedron

54. Octahedron. — The *octahedron*, shown in Fig. 93, has the general symbol (111). It is bounded by eight similar faces, each meeting the three axes at equal distances. Each face is an equilateral triangle with plane angles of 60°. The normal interfacial angle, ($111 \wedge 1\bar{1}1$), is 70° 31′ 44″.

55. Dodecahedron. — The *rhombic dodecahedron*,† shown in Fig. 94, has the general symbol (110). It is bounded by twelve faces, each of which meets two of the axes at equal distances and is parallel to the third axis. Each face is a rhomb with plane angles of 70½° and 109½°. The normal interfacial angle is 60°. The faces of the dodecahedron are parallel to the six auxiliary, or diagonal, planes of symmetry.

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* The usage followed here (as also in the other systems) is in most cases that of Miller (1852).

† The *dodecahedron* of the crystallographer is this form with rhombic shaped faces commonly found on crystals of garnet. Geometricians recognize various solids bounded by twelve similar faces; of these the regular (pentagonal) dodecahedron is the most important. In crystallography this solid is impossible though the *pyritohedron* approximates to it. (See Art. 68.)

It will be remembered that, while the forms described are designated respectively by the symbols (100), (111), and (110), each face of any one of the forms has its own indices. Thus for the *cube* the six faces have the indices

$$100,\quad 010,\quad 001,\quad \bar{1}00,\quad 0\bar{1}0,\quad 00\bar{1}.$$

For the *octahedron* the indices of the eight faces are:

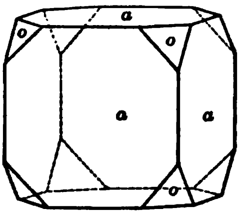
$$\begin{array}{lllll} \text{Above} & 111, & \bar{1}11, & \bar{1}\bar{1}1, & 1\bar{1}1; \\ \text{Below} & 11\bar{1}, & \bar{1}1\bar{1}, & \bar{1}\bar{1}\bar{1}, & 1\bar{1}\bar{1}. \end{array}$$

For the *dodecahedron* the indices of the twelve faces are:

$$\begin{array}{llll} 110, & \bar{1}10, & \bar{1}\bar{1}0, & 1\bar{1}0, \\ 101, & \bar{1}01, & \bar{1}0\bar{1}, & 10\bar{1}, \\ 011, & 0\bar{1}1, & 0\bar{1}\bar{1}, & 01\bar{1}. \end{array}$$

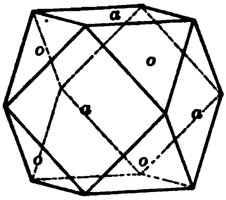
These should be carefully studied with reference to the figures (and to models), and also to the projections (Figs. 125, 126). The student should become thoroughly familiar with these individual indices and the relations to the axes which they express, so that he can give at once the indices of any face required.

95



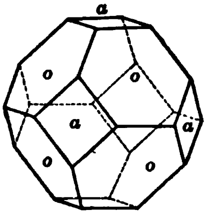
Cube and Octahedron

96



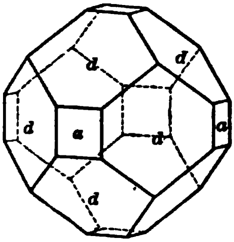
Cube and Octahedron

97



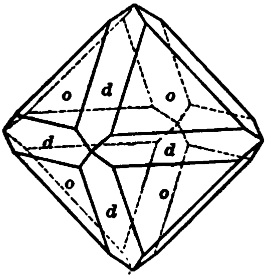
Octahedron and Cube

98



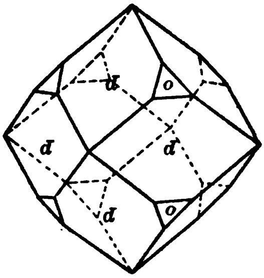
Dodecahedron and Cube

99



Octahedron and Dodecahedron

100

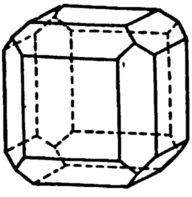


Dodecahedron and Octahedron

56. Combinations of the Cube, Octahedron, and Dodecahedron. — Figs. 95, 96, 97 represent combinations of the cube and octahedron; Figs. 98, 101 of the cube and dodecahedron; Figs. 99, 100 of the octahedron and dodecahedron; finally, Figs. 102, 103 show combinations of the three forms. The predominating form, as the cube in Fig. 95, the octahedron in Fig. 97, etc., is usually said to be *modified* by the faces of the other forms. In Fig. 96 the cube and octahedron are sometimes said to be "in equilibrium," since the faces of the octahedron meet at the middle points of the edges of the cube.

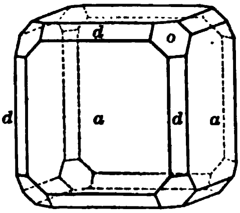
It should be carefully noticed, further, that the octahedral faces replace the solid angles of the cube, as regular triangles equally inclined to the adjacent cubic faces, as shown in Fig. 95. Again, the square cubic faces replace the six solid angles of the octahedron, being equally inclined to the adjacent octahedral faces (Fig. 97). The faces of the dodecahedron *truncate* * the twelve similar edges of the cube, as shown in Fig. 101. They also truncate the twelve edges of the octahedron (Fig. 99). Further, in Fig. 98 the cubic faces replace the six tetrahedral solid angles of the dodecahedron, while the octahedral faces replace its eight trihedral solid angles (Fig. 100).

101



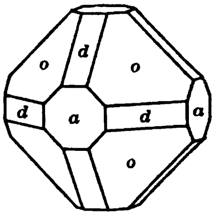
Cube and Dodecahedron

102



Cube, Octahedron and Dodecahedron

103



Octahedron, Cube and Dodecahedron

The normal interfacial angles for adjacent faces are as follows:

Cube on octahedron, *ao*. 100 ∧ 111 = 54° 44′ 8″.
Cube on dodecahedron, *ad*, 100 ∧ 110 = 45° 0′ 0″.
Octahedron on dodecahedron, *od*, 111 ∧ 110 = 35° 15′ 52″.

57. As explained in Art. **18** actual crystals always deviate more or less widely from the ideal solids figured, in consequence of the unequal development of like faces. Such crystals, therefore, do not satisfy the *geometrical* definition of right symmetry relatively to the three principal and the six auxiliary planes mentioned on p. 53 but they do conform to the conditions of crystallographic symmetry, requiring like angular position for similar faces. Again, it will be noted that in a combination form many of the faces do not actually meet the axes within the crystal, as, for example, the octahedral face *o* in Fig. 95. It is still true, however, that this face would meet the axes at equal distances if produced; and since the *axial ratio* is the essential point in the case of each form, and the *actual lengths* of the axes are of no importance, it is not necessary that the faces of the different forms in a crystal should be referred to the same actual axial lengths. The above remarks will be seen to apply also to all the other forms and combinations of forms described in the pages following.

58. Tetrahexahedron. — The *tetrahexahedron* (Figs. 104, 105, 106) is bounded by twenty-four faces, each of which is an isosceles triangle. Four of these faces together occupy the position of one face of the cube (hexahedron) whence the name commonly applied to this form. The general symbol is (*hk*0), hence each face is parallel to one of the axes while it meets the other two axes at unequal distances which are definite multiples of each other. There are two kinds of edges, lettered *A* and *C* in Fig. 104; the interfacial angle of either edge is sufficient to determine the symbol of a given form (see below). The angles of some of the common forms are given on a later page (p. 63).

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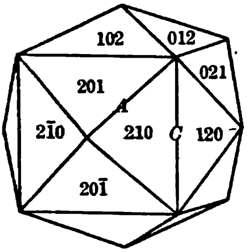
* The words *truncate*, *truncation*, are used only when the modifying face makes equal angles with the adjacent similar faces.

There may be a large number of tetrahexahedrons, as the ratio of the intercepts of the two axes, and hence of h to k varies; for example, (410), (310), (210), (320), etc. The form (210) is shown in Fig. 104; (410) in Fig. 105, and (530) in Fig. 106. All the tetrahexahedrons fall in a zone with a cubic face and a dodecahedral face. As h increases relatively to k the form approaches the cube (in which $h : k = \infty : 1$ or $1 : 0$), while as it diminishes and becomes more and more nearly equal to k in value it approaches the dodecahedron; for which $h = k$. Compare Fig. 105 and Fig. 106; also Figs. 125, 126. The special symbols belonging to each face of the tetrahexahedron should be carefully noted.

104



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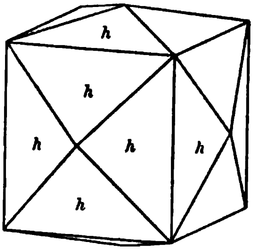

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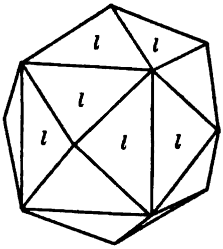
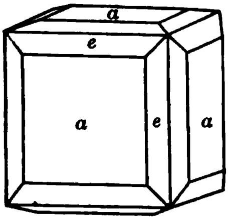


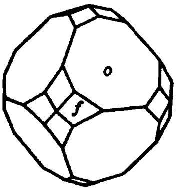
Tetrahexahedrons

107



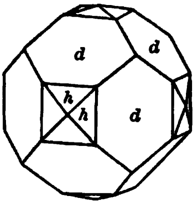
Cube and Tetrahexahedron

108



Octahedron and Tetrahexahedron

109



Dodecahedron and Tetrahexahedron

The faces of the tetrahexahedron bevel * the twelve similar edges of the cube, as in Fig. 107; they replace the solid angles of the octahedron by four faces inclined on the edges (Fig. 108; $f = 310$), and also the tetrahedral solid angles of the dodecahedron by four faces inclined on the faces (Fig. 109; $h = 410$).

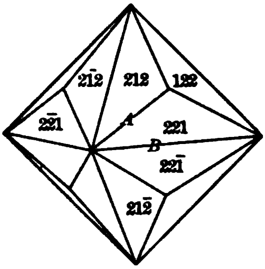
59. Trisoctahedron. — The *trisoctahedron* (Fig. 110) is bounded by twenty-four similar faces; each of these is an isosceles triangle, and three together occupy the position of an octahedral face, whence the common name. Further, to distinguish it from the trapezohedron (or tetragonal trisoctahedron), it is sometimes called the *trigonal trisoctahedron.* There are two kinds of edges, lettered A and B in Fig. 110, and the interfacial angle corresponding to either is sufficient for the determination of the special symbol.

---

* The word *bevel* is used when two like faces replace the edge of a form and hence are inclined at equal angles to its adjacent similar faces.

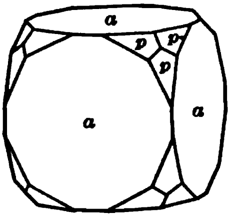
The general symbol is (*hhl*); common forms are (221), (331), etc. Each face of the trisoctahedron meets two of the axes at a distance less than unity and the third at the unit length, or (which is an identical expression *) it meets two of the axes at the unit length and the third at a distance greater than unity. The indices belonging to each face should be carefully noted. The normal interfacial angles for some of the more common forms are given on a later page.

110



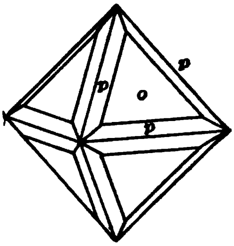
Trisoctahedron

111



Cube and Trisoctahedron

112



Octahedron and Trisoctahedron

60. Trapezohedron. — The *trapezohedron* † (Figs. 113, 114) is bounded by twenty-four similar faces, each of them a quadrilateral or trapezium. It also bears in appearance a certain relation to the octahedron, whence the name, sometimes employed, of *tetragonal trisoctahedron.* There are two kinds of edges, lettered *B* and *C*, in Fig. 113. The general symbol is *hll*; common forms are (311), (211), (322), etc. Of the faces, each cuts an axis at a distance less than unity, and the other two at the unit length, or (again, an identical expression) one of them intersects an axis at the unit length and the other two at equal distances greater than unity. The indices belonging to each face should be carefully noted. The normal interfacial angles for some of the common forms are given on a later page. Another name for this form is *icositetrahedron.*

61. The combinations of these forms with the cube, octahedron, etc., should be carefully studied. It will be seen (Fig. 111) that the faces of the trisoctahedron replace the solid angles of the cube as three faces equally inclined on the *edges;* this is a combination which has not been observed on crystals. The faces of the trapezohedron appear as three equal triangles equally inclined to the cubic faces (Fig. 115).

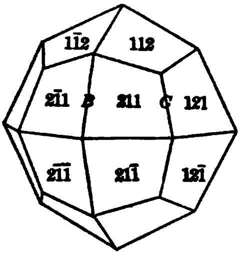
Again, the faces of the trisoctahedron bevel the edges of the octahedron, Fig. 112, while those of the trapezohedron are triangles inclined to the faces at the extremities of the cubic axes, Fig. 119; *m*(311). Still again, the faces of the trapezohedron *n*(211) truncate the edges of the dodecahedron (110), as shown in Fig. 118; this can be proved to follow at once from the zonal relations (Arts. 45, 46), cf. also Figs. 125, 126. The position of the faces of the form *m*(311), in combination with *o*, is shown in Fig. 119; with *d* in Fig. 120.

---

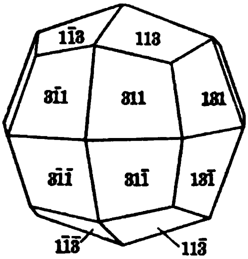
* Since $\frac{1}{2}a : \frac{1}{2}b : \frac{1}{1}c = 1a : 1b : 2c$. The student should read again carefully the explanations in Art. **35.**

† It will be seen later that the name trapezohedron is also given to other solids whose faces are trapeziums conspicuously to the tetragonal trapezohedron and the trigonal trapezohedron.

113



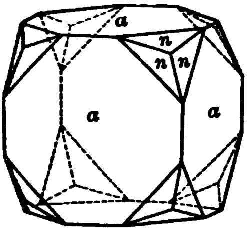
114



Trapezohedrons

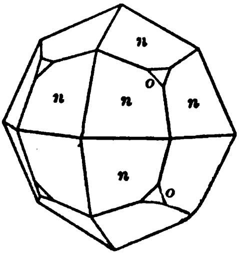
It should be added that the trapezohedron *n*(211) is a common form both alone and in combination; *m*(311) is common in combination. The trisoctahedron alone is rarely met with, though in combination (Fig. 112) it is not uncommon.

115



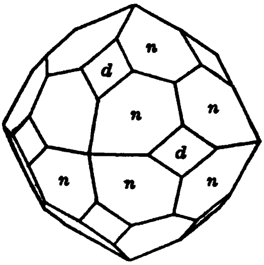
Analcite. Cube and Trapezohedron

116



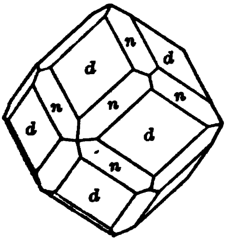
Analcite. Trapezohedron and Octahedron

117



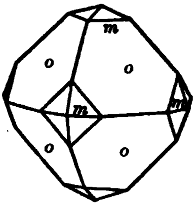
Garnet. Trapezohedron and Dodecahedron

118



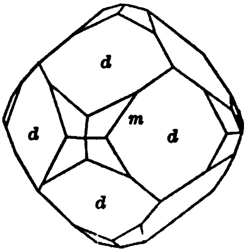
Garnet. Dodecahedron and Trapezohedron

119



Spinel. Octahedron and Trapezohedron

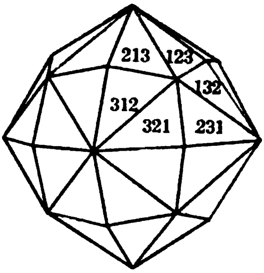
120



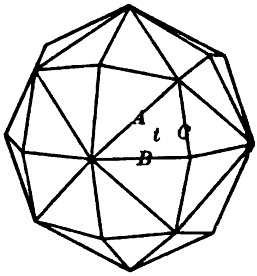
Magnetite. Dodecahedron and Trapezohedron

62. Hexoctahedron. — The *hexoctahedron*, Figs. 121, 122, is the general form in this system; it is bounded by forty-eight similar faces, each of which is a scalene triangle, and each intersects the three axes at unequal distances. The general symbol is (*hkl*); common forms are *s*(321), shown in Fig. 121, and *t*(421), in Fig. 122 The indices of the individual faces, as shown in Fig. 121 and more fully in the projections (Figs. 125, 126), should be carefully studied.

121

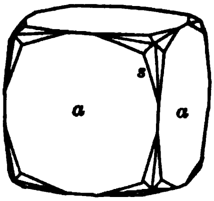


122



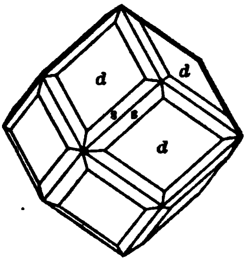
The hexoctahedron has three kinds of edges lettered *A*, *B*, *C* (longer, middle, shorter) in Fig. 122; the angles of two of these edges are needed to fix the symbol unless the zonal relation can be made use of In Fig. 124 the faces of the hexoctahedron bevel the dodecahedral edges, and hence for this form $h = k + l$; the form *s* has the special symbol (321). The hexoctahedron alone is a very rare form, but it is seen in combination with the cube (Fig 123, fluorite) as six small faces replacing each solid angle. Fig. 124 is common with garnet.

123



Fluorite Cube and Hexoctahedron

124



Garnet. Dodecahedron and Hexoctahedron

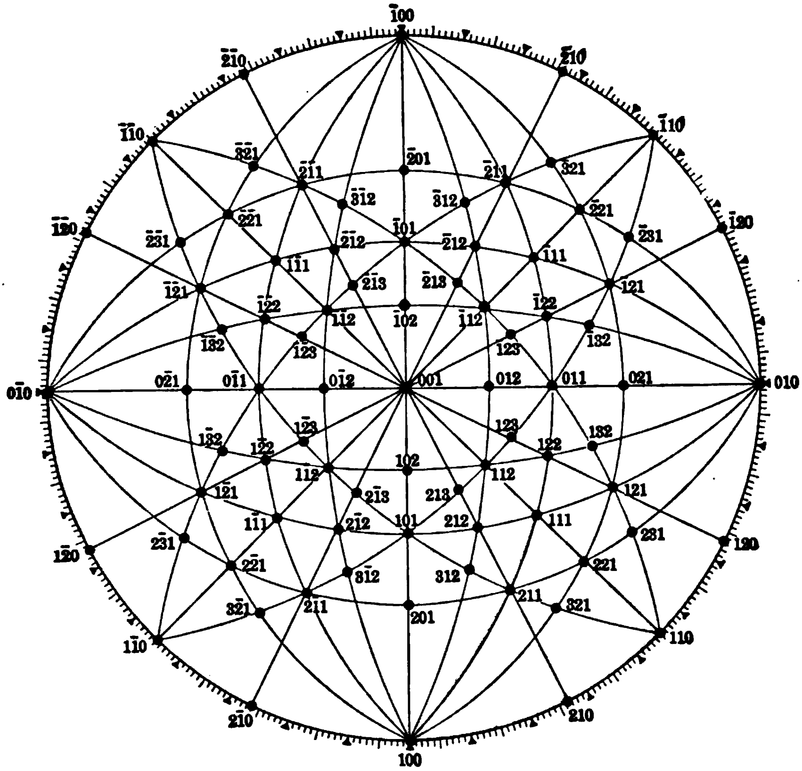
64. Pseudo-symmetry in the Isometric System. — Isometric forms, by development in the direction of one of the cubic axes, simulate tetragonal forms. More common, and of greater interest, are forms simulating those of rhombohedral symmetry by extension, or by flattening, in the direction of an octahedral axis. Both these cases are illustrated later. Conversely, certain rhombohedral forms resemble an isometric octahedron in angle.

65. Stereographic and Gnomonic Projections. — The stereographic projection, Fig. 125, and gnomonic projection, Fig. 126, show the positions of the poles of the faces of the cube (100), octahedron (111), and dodecahedron (110); also the tetrahexahedron (210), the trisoctahedron (221), the trapezohedron (211), and the hexoctahedron (321).

The student should study this projection carefully, noting the symmetry marked by the zones 100. 001, $\bar{1}00$, and 100, 010, $\bar{1}00$; also by 110, 001, $\bar{1}\bar{1}0$; $1\bar{1}0$, $00\bar{1}$, $\bar{1}10$; 010, 101, $0\bar{1}0$; 010, $\bar{1}01$, $0\bar{1}0$. Note further that the faces of a given form are symmetrically distributed about a cubic face, as 001; a dodecahedral face, as 101; an octahedral face, as 111.

Note further the symbols that belong to the individual faces of each form, comparing the projections with the figures which precede.

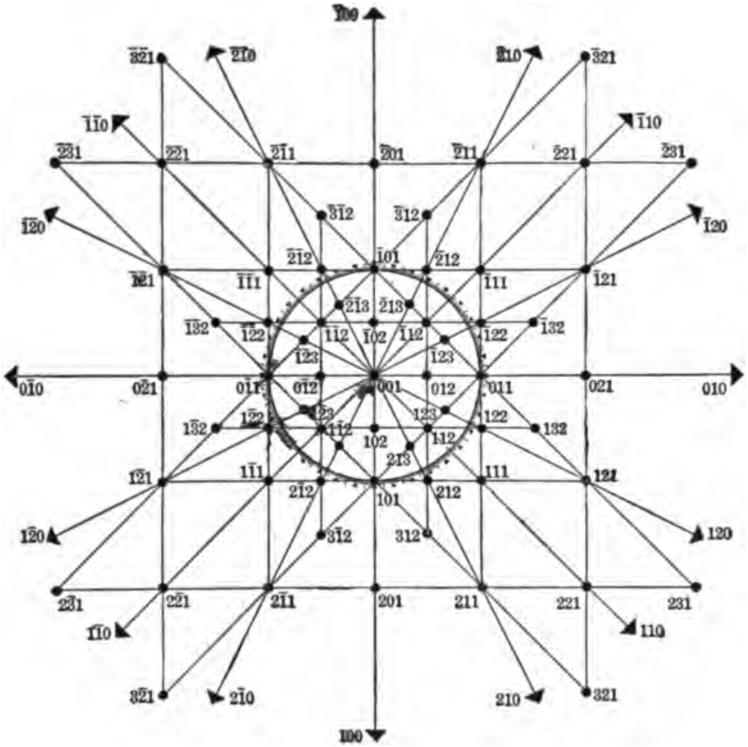
125



Stereographic Projection of Isometric Forms (Cube (100), Octahedron (111), Dodecanedron (110), Tetrahexahedron (210), Trisoctahedron (221), Trapezohedron (211), Hexoctahedron (321))

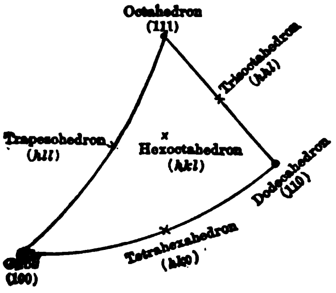
Finally, note the prominent *zones of planes;* for example, the zone between two cubic faces including a dodecahedral face and the faces of all possible tetrahexahedrons. Again, the zones from a cubic face (as 001) through an octahedral face (as 111) passing through the trisoctahedrons, as 113, 112, 223, and the trapezohedrons 332, 221, 331, etc. Also the zone from one dodecahedral face, as 110, to another, as 101, passing through 321, 211, 312, etc. At the same time compare these zones with the same zones shown on the figures already described. A study of the relations illustrated in Fig. 127 will be found useful. From it is seen that any crystal face falling in the zone between the cube and dodecahedron must belong to a tetrahexahedron; any face falling in the zone between the cube and octahedron must belong to a trapezohedron; and any face falling in the zone between the octahedron and dodecahedron must belong to a trisoctahedron, further any face falling outside these three zones must belong to a hexoctahedron.

126

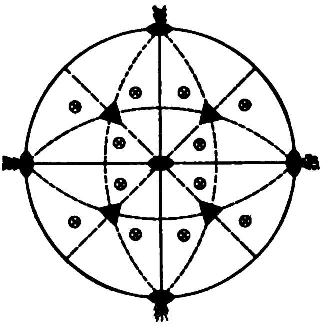


Gnomonic Projection of Isometric Forms (Cube (100), Octahedron (111), Dodecahedron (110), Tetrahexahedron (210), Trisoctahedron (221), Trapezohedron (211), Hexoctahedron (321))

127



128



Symmetry of Pyritohedral class

66. Angles of Common Isometric Forms.*

TETRAHEXAHEDRONS.

	Edge A	Edge C	Angle on	Angle on
Cf. Fig. 104.	210 ∧ 201, etc.	210 ∧ 120, etc.	*a*(100)	*o*(111)
410	19° 45′	61° 55¾′	14° 2¼′	45° 33¾′
310	25 50½	53 17¾	18 26	43 5¼
520	30 27	46 23¾	21 48	41 22
210	36 52¼	36 52¼	26 34	39 14
530	42 40	28 4¼	30 57¾	37 37
320	46 11¼	22 37¼	33 41½	36 48½
430	50 12½	16 15½	36 52¼	36 4¼
540	52 25¾	12 40¾	38 39½	35 45½

TRISOCTAHEDRONS.

	Edge A	Edge B	Angle on	Angle on
Cf. Fig. 110.	221 ∧ 212; etc.	221 ∧ 22$\bar{1}$, etc.	*a*(100)	*o*(111)
332	17° 20½′	50° 28¾′	50° 14¼′	10° 1½′
221	27 16	38 56½	48 11	15 47½
552	33 33½	31 35¼	47 7½	19 28¼
331	37 51¾	26 31½	46 30½	22 0
772	40 59	22 50½	46 7½	23 50½
441	43 20½	20 2¾	45 52	25 14¼

TRAPEZOHEDRONS.

	Edge B	Edge C	Angle on	Angle on
Cf. Fig. 113.	211 ∧ 2$\bar{1}$1, etc	211 ∧ 121, etc.	*a*(100)	*o*(111)
411	27° 16′	60° 0′	19° 28¼	35° 15¾′
722	30 43¼	55 50¾	22 0	32 44
311	35 5¾	50 28¾	25 14¼	29 29¾
522	40 45	43 20½	29 29¾	25 14¼
211	48 11½	33 33½	35 15¾	19 28¼
322	58 2	19 45	43 18¾	11 25¼

HEXOCTAHEDRONS.

	Edge A	Edge B	Edge C	Angle on	Angle on
Cf. Fig. 121.	321 ∧ 312, etc.	321 ∧ 32$\bar{1}$, etc.	321 ∧ 231, etc.	*a*(100)	*o*(111)
421	17° 45¼′	25° 12½′	35° 57′	29° 12¼′	28° 6½′
531	27 39½	19 27¾	27 39½	32 18¾	28 33¾
321	21 47¼	31 0¼	21 47¼	36 42	22 12½
432	15 5½	43 36¼	15 5½	42 1¾	15 13½
431	32 12¼	22 37¼	15 56½	38 19¾	25 4

2. PYRITOHEDRAL CLASS (2). PYRITE TYPE

(*Dyakisdodecahedral or Pentagonal Hemihedral Class*)

67. Typical Forms and Symmetry. — The typical forms of the pyritohedral class are the *pyritohedron*, or pentagonal dodecahedron, Figs. 129, 130, and the *diploid*, or dyakisdodecahedron, Fig. 135. The symmetry of these forms, as of the class as a whole, is as follows: The three crystallographic axes are axes of binary symmetry only; there are also four diagonal axes of trigonal symmetry coinciding with the octahedral axes. There are but three planes of symmetry; these coincide with the planes of the crystallographic axes and are parallel to the faces of the cube.

The stereographic projection in Fig. 128 shows the distribution of the faces of the general form (*hkl*), diploid, and thus exhibits the symmetry of the class. This should be carefully compared with the corresponding projection (Fig. 91) for the normal class, so that the lower grade of symmetry here present be thoroughly understood. In studying the forms described and illustrated in the following pages, this matter of symmetry, especially in relation to that of the normal class, should be continually before the mind.

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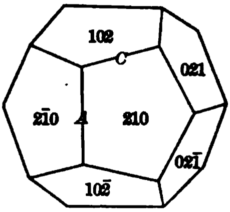
* A fuller list is given in the Introduction to Dana's System of Mineralogy, 1892, pp. xx–xxiii.

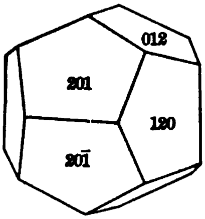
It will be observed that the faces of both the pyritohedron (Fig. 129) and the diploid (Fig. 135) are arranged in parallel pairs, and on this account these forms have been sometimes called *parallel hemihedrons.* Further, those authors who prefer to describe these forms as cases of hemihedrism call this type parallel-faced hemihedrism or pentagonal hemihedrism.

68. Pyritohedron. — The *pyritohedron* (Fig. 129) is so named because it is a typical form with the common species, pyrite. It is a solid bounded by twelve faces, each of which is a pentagon, but with one edge (*A*, Fig. 129) longer than the other four similar edges (*C*). It is often called a pentagonal dodecahedron, and indeed it resembles closely the regular dodecahedron of geometry, in which the faces are regular pentagons. This latter form is, however, an impossible form in crystallography.

129

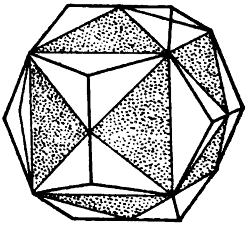


130



Pyritohedrons

131



Showing Relation between Pyritohedron and Tetrahexahedron

The general symbol is (*hk*0) or like that of the tetrahexahedron of the normal class. Hence each face is parallel to one of the axes and meets the other two axes at unequal distances. Common forms are (410), (310), (210), (320), etc. Besides the positive pyritohedron, as (210), there is also the complementary negative form * shown in Fig. 130; the symbol is here (120). Other common forms are (250), (230), (130), etc.

The positive and negative pyritohedrons together embrace twenty-four faces, having the same position as the twenty-four like faces of the tetrahexahedron of the normal class. The relation between the tetrahexahedron and the pyritohedron is shown in Fig. 131, where the alternate faces of the tetrahexahedron (indicated by shading) are extended to form the faces of the pyritohedron.

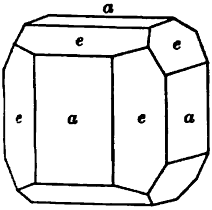
69. Combinations. — The faces of the pyritohedron replace the edges of the cube as shown in Fig. 132; this resembles Fig. 101 but here the faces make unequal angles with the two adjacent cubic faces. On the other hand, when the pyritohedron is modified by the cube, the faces of the latter truncate the longer edges of the pentagons.

---

* The negative forms in this and similar cases have sometimes distinct letters, sometimes the same as the positive form, but are then distinguished by a subscript accent, as *e*(210) and *e*, (120).

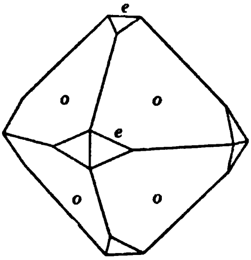
Fig. 133 shows the combination of the pyritohedron and octahedron, and in Fig. 134 these two forms are equally developed. The resulting combination bears a close similarity to the *icosahedron*, or regular twenty-faced solid, of geometry. Here, however, of the twenty faces, the eight octahedral are equilateral triangles, the twelve others belonging to the pyritohedron are isosceles triangles.

132



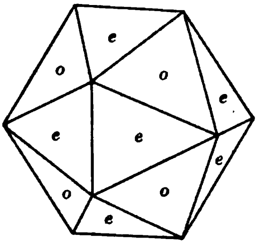
Cube and Pyritohedron

133



Octahedron and Pyritohedron

134

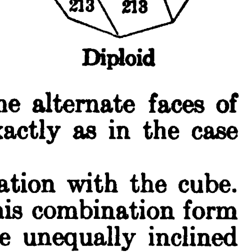


Octahedron and Pyritohedron

70. Diploid. — The *diploid* is bounded by twenty-four similar faces, each meeting the axes at unequal distances; its general symbol is hence (*hkl*), and common forms are *s*(321), *t*(421), etc. The form (321) is shown in Fig. 135; the symbols of its faces, as given, should be carefully studied. As seen in the figure, the faces are quadrilaterals or trapeziums; moreover, they are grouped in pairs, hence the common name diploid. It is also sometimes called a dyakisdodecahedron.

The complementary negative form bears to the positive form of Fig. 135 the same relation as the negative to the positive pyritohedron. Its faces have the symbols 312, 231, 123, in the front octant, and similarly with the proper negative signs in the others. The positive and negative forms together obviously embrace all the faces of the hexoctahedron of the normal class. The diploid can be considered to be derived from the hexoctahedron by the extension of the alternate faces of the latter and the omission of the remaining faces, exactly as in the case of the pyritohedron and tetrahexahedron (Art. 68).

135

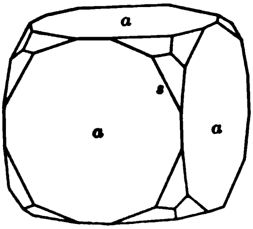


Diploid

In Fig. 136 the positive diploid is shown in combination with the cube. Here the three faces replace each of its solid angles. This combination form resembles that of Fig. 111, but the three faces are here unequally inclined upon two adjacent cubic faces. Other combinations of the diploid with the cube, octahedron, and pyritohedron are given in Figs. 137 and 138.

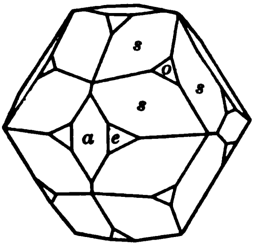
71. Other Forms. — If the pyritohedral type of symmetry be applied to planes each parallel to two of the axes, it is seen that this symmetry calls for six of these, and the resulting form is obviously a cube. This cube cannot be distinguished geometrically from the cube of the normal class, but it has its own characteristic molecular symmetry. Corresponding to this it is common to find cubes of pyrite with fine lines (striations) parallel to the alternate edges, as indicated in Fig. 139. These are due to the partial development of pyritohedral faces (210). On a normal cube similar striations, if present, must be parallel to both sets of edges on each cubic face.

136



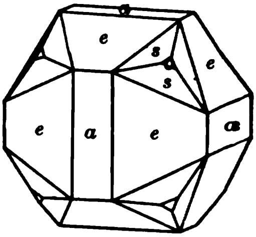
Cube and Diploid

137



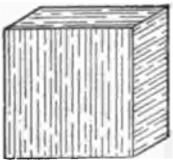
Cube, Octahedron and Diploid

138



Cube, Diploid and Pyritohedron

139



Pyrite. Striated Cube

Similarly to the cube, the remaining forms of this pyritohedral class, namely, (111), (110), (*hhl*), (*hll*), have the same geometrical form, respectively, as the octahedron, dodecahedron, the trisoctahedrons and trapezohedrons of the normal class. In molecular structure, however, these forms are distinct, each having the symmetry described in Art. **67**.

72. Angles. — The following tables contain the angles of some common forms.

Pyritohedrons.

	Edge A	Edge C	Angle on	Angle on
Cf. Fig. 129.	210 ∧ 2̄10, etc.	210 ∧ 102, etc.	*a*(100)	*o*(111)
410	28° 4¼′	76° 23½′	14° 2¼′	45° 33¾′
310	36 52¼	72 32½	18 26	43 5¼
520	43 36¼	69 49¾	21 48	41 22
210	53 7¾	66 25¼	26 34	39 14
530	61 55¾	63 49¼	30 57¾	37 37
320	67 22¾	62 30¾	33 41½	36 48½
430	73 44½	61 19	36 52¼	36 4¼
540	77 19¼	60 48¼	38 39½	35 45¾
650	79 36¾	60 32½	39 48¼	35 35¾

Diploids.

	Edge A	Edge B	Edge C	Angle on	Angle on
Cf. Fig. 135.	321 ∧ 32̄1, etc.	321 ∧ 321̄, etc.	321 ∧ 213, etc.	*a*(100)	*o*(111)
421	51° 45¼′	25° 12½′	48° 11½′	29° 12¼′	28° 6½′
532	58 14½	37 51¾	35 20	35 47¾	20 30¾
531	60 56½	19 27¼	19 27¾	32 18¾	28 33¾
851	63 36¾	12 6	53 55¼	32 30¾	31 34
321	64 37½	31 0¼	38 12¼	36 42	22 12½
432	67 42½	43 36¼	26 17½	42 1¾	15 13½
431	72 4¾	22 37¼	43 3	38 19¾	25 4

3. TETRAHEDRAL CLASS (3). TETRAHEDRITE TYPE

(*Hextetrahedral, Tetrahedral Hemihedral Class*)

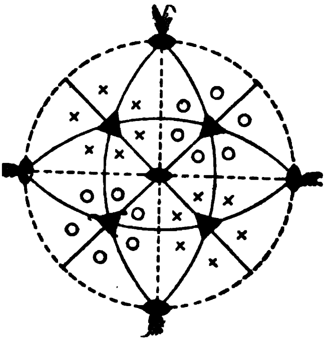
73. Typical Forms and Symmetry. — The typical form of this class, and that from which it derives its name, is the *tetrahedron,* shown in Figs.

141, 142. There are also three other distinct forms, shown in Figs. 149, 150, 151.

The symmetry of this class is as follows. There are three axes of binary symmetry which coincide with the crystallographic axes. There are also four diagonal axes of trigonal symmetry which coincide with the octahedral axes. There are six diagonal planes of symmetry. There is no center of symmetry.

The stereographic projection (Fig. 140) shows the distribution of the faces of the general form (*hkl*), hextetrahedron, and thus exhibits the symmetry of the class. It will be seen at once that the like faces are all grouped in the *alternate octants*, and this will be seen to be characteristic of all the forms peculiar to this class. The relation between the symmetry here described and that of the normal class must be carefully studied.

140

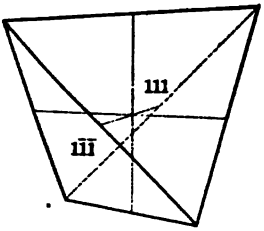


Symmetry of Tetrahedral Class

In distinction from the pyritohedral forms whose faces were in parallel pairs, the faces of the tetrahedron and the analogous solids are inclined to each other, and hence they are sometimes spoken of as *inclined hemihedrons*, and the type of so-called hemihedrism here illustrated is then called inclined or tetrahedral hemihedrism.

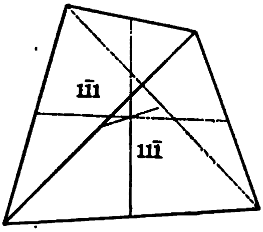
74. Tetrahedron. — The tetrahedron,* as its name indicates, is a four-faced solid, bounded by planes meeting the axes at equal distances. Its general symbol is (111), and the four faces of the positive form (Fig. 141) have the symbols 111, $\bar{1}\bar{1}1$, $1\bar{1}\bar{1}$, $\bar{1}1\bar{1}$. These correspond to four of the faces of the octahedron of the normal class (Fig. 93). The relation between the two forms is shown in Fig. 143.

141



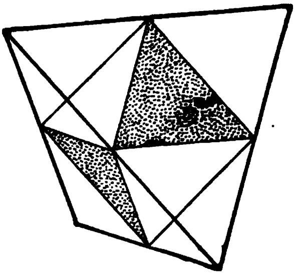
Positive Tetrahedron

142



Negative Tetrahedron

143



Showing Relation between Octahedron and Tetrahedron

Each of the four faces of the tetrahedron is an equilateral triangle; the (normal) interfacial angle is 109° 29′ 16″. The tetrahedron is the regular triangular pyramid of geometry, but crystallographically it must be so placed that the axes join the middle points of opposite edges, and one axis is vertical.

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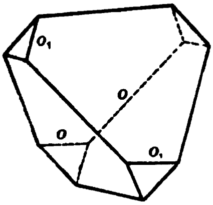
* This is one of the five regular solids of geometry, which include also the cube, octahedron, the regular pentagonal dodecahedron, and the icosahedron; the last two, as already noted, are impossible forms among crystals.

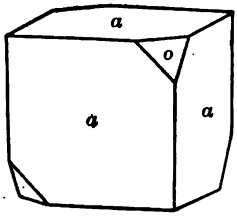
There are two possible tetrahedrons: the positive tetrahedron (111), designated by the letter *o*, which has already been described, and the negative tetrahedron, having the same geometrical form and symmetry, but the indices of its four faces are $\bar{1}11$, $1\bar{1}\bar{1}$, $11\bar{1}$, $\bar{1}\bar{1}\bar{1}$. This second form is shown in Fig. 142; it is usually designated by the letter o_1. These two forms are, as stated above, identical in geometrical shape, but they may be distinguished in many cases by the tests which serve to reveal the molecular structure, particularly the etching-figures; also in many cases by pyro-electricity (see under boracite, p. 306), Art. **438.** It is probable that the positive and negative tetrahedrons of sphalerite (see that species) have a constant difference in this particular, which makes it possible to distinguish them on crystals from different localities and of different habit.

144



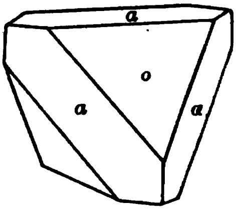
Positive and Negative Tetrahedrons

145



Cube and Tetrahedron

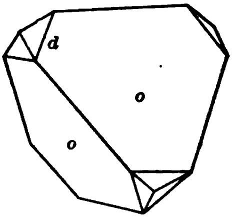
146



Tetrahedron and Cube

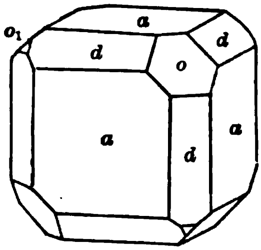
If both tetrahedrons are present together, the form in Fig. 144 results. This is geometrically an octahedron when the two forms are equally developed, but crystallographically it is always only a combination of two unlike forms, the positive and negative tetrahedrons, which can be distinguished as already noted.

147



Tetrahedron and Dodecahedron

148

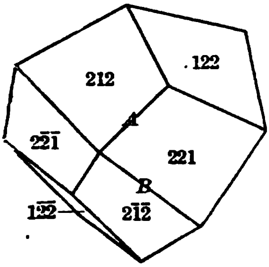


Boracite. Cube, Dodecahedron with Positive and Negative Tetrahedrons

The tetrahedron in combination with the cube replaces the alternate solid angles as in Fig. 145. The cube modifying the tetrahedron truncates its edges as shown in Fig. 146. The normal angle between adjacent cubic and tetrahedral faces is 54° 44′. In Fig. 147 the dodecahedron is shown modifying the positive tetrahedron, while in Fig. 148 the cube is the predominating form with the positive and negative tetrahedrons and dodecahedron.

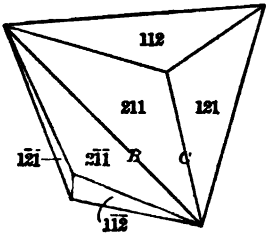
75. Other Typical Forms. — There are three other distinct types of solids in this class, having the general symbols (*hhl*), (*hll*), and (*hkl*). The first of these is shown in Fig. 149; here the symbol is (221). There are twelve faces, each a quadrilateral, belonging to this form, distributed as determined by the tetrahedral type of symmetry. They correspond to twelve of the faces of the trisoctahedron, namely, all those falling in alternate octants. This type of solid is sometimes called a *tetragonal tristetrahedron*, or a deltoid dodecahedron. It does not occur alone among crystals, but its faces are observed modifying other forms

149



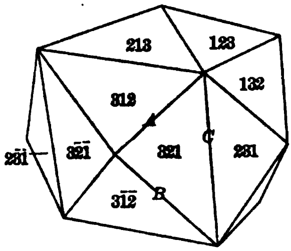
Tetragonal Tristetrahedron

150



Trigonal Tristetrahedron

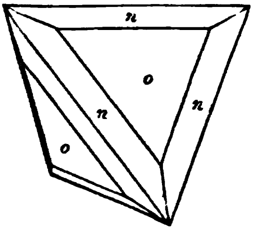
151



Hextetrahedron

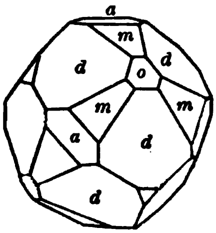
There is also a complementary negative form, corresponding to the positive form, related to it in precisely the same way as the negative to the positive tetrahedron. Its twelve faces are those of the trisoctahedron which belong to the other set of alternate octants.

152



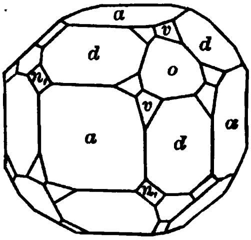
Tetrahedrite

153



Sphalerite

154



Boracite.

Another form, shown in Fig. 150, has the general symbol (*hll*), here (211); it is bounded by twelve like triangular faces, distributed after the type demanded by tetrahedral symmetry, and corresponding consequently to the faces of the alternate octants of the form (*hll*) — the trapezohedron — of the normal class. This type of solid is sometimes called a *trigonal tristetrahedron* or trigondodecahedron.* It is observed both alone and in combination, especially with the species tetrahedrite; it is much more common than the form (*hhl*). There is here again a complementary negative form. Fig. 152 shows the positive form *n*(211) with the positive tetrahedron, and Fig. 153 the form *m*(311) with *a*(100), *o*(111), and *d*(110). In Fig. 154, the negative form *n*,(2$\bar{1}$1) is present.

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* It is to be noted that the tetragonal tristetrahedron has faces which resemble those of the trapezohedron (tetragonal trisoctahedron), although it is related not to this but to the trisoctahedron (trigonal trisoctahedron). On the other hand, the faces of the trigonal tristetrahedron resemble those of the trisoctahedron, though in fact related to the trapezohedron.

The fourth independent type of solids in this class is shown in Fig. 151. It has the general symbol (*hkl*), here (321), and is bounded by twenty-four faces distributed according to tetrahedral symmetry, that is, embracing all the faces of the alternate octants of the forty-eight-faced hexoctahedron. This form is sometimes called a *hextetrahedron* or *hexakistetrahedron.* The complementary negative form (*h*$\bar{k}$*l*) embraces the remaining faces of the hexoctahedron. The positive hextetrahedron, *v*(531), is shown in Fig. 154 with the cube, octahedron, and dodecahedron, also the negative trigonal tristetrahedron *n*,(2$\bar{1}$1).

76. If the tetrahedral symmetry be applied in the case of planes each parallel to the two axes, it will be seen that there must be six such faces. They form a *cube* similar geometrically to the cube both of the normal and pyritohedral class but differing in its molecular structure, as can be readily proved, for example, by pyro-electricity (Art. 438). Similarly in the case of the planes having the symbol (110), there must be twelve faces forming a rhombic dodecahedron bearing the same relation to the like geometrical form of the normal class. The same is true again of the planes having the position expressed by the general symbol (*hk*0); there must be twenty-four of them and they together form a tetrahexahedron.

In this class, therefore, there are also seven types of forms, but only four of them are geometrically distinct from the corresponding forms of the normal class.

77. Angles. — The following tables contain the angles of some common forms:

TETRAGONAL TRISTETRAHEDRONS.

	Edge A	Edge B	Angle on	Angle on
Cf. Fig. 149.	221 $\wedge$ 212, etc.	221 $\wedge$ 2$\bar{1}\bar{2}$, etc.	*a*(100)	*o*(111)
332	17° 20½′	97° 50¼′	50° 14¼′	10° 1½′
221	27 16	90 0	48 11½	15 47½
552	33 33½	84 41	47 7½	19 28¼
331	37 51¾	80 55	46 30½	22 0

TRIGONAL TRISTETRAHEDRONS.

	Edge B	Edge C	Angle on	Angle on
Cf. Fig. 150	211 $\wedge$ 2$\bar{1}\bar{1}$, etc.	211 $\wedge$ 121, etc.	*a*(100)	*o*(111)
411	38° 56½′	60° 0′	19° 28¼′	35° 15¾′
722	44 0¼	55 50¾	22 0	32 44
311	50 28¾	50 28¾	25 14¼	29 29¾
522	58 59½	43 20½	29 29¾	25 14¼
211	70 31¾	33 33½	35 15¾	19 28¼
322	86 37¾	19 45	43 18¾	11 25¼

HEXTETRAHEDRONS.

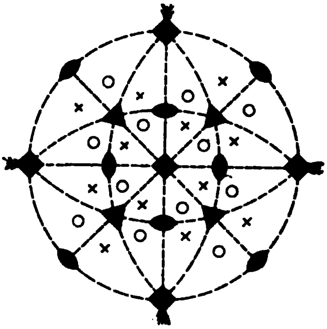
	Edge A	Edge B	Edge C	Angle on	Angle on
Cf. Fig. 151.	321 $\wedge$ 312, etc.	321 $\wedge$ 3$\bar{1}\bar{2}$, etc.	321 $\wedge$ 231, etc.	*a*(100)	*o*(111)
531	27° 39¾′	57° 7¼′	27° 39¾′	32° 18¾′	28° 33¾′
321	21 47¼	69 4½	21 47¼	36 42	22 12½
432	15 5½	82 4¼	15 5½	42 1¾	15 13½
431	32 12¼	67 22¾	15 56½	38 19¾	25 4

4. PLAGIOHEDRAL CLASS (4). CUPRITE TYPE.

(*Pentagonal Icositetrahedral, Plagiohedral Hemihedral Class*)

78. Typical Forms and Symmetry. — The fourth class under the isometric system is called the plagiohedral or gyroidal class because the faces of the general form (*hkl*) are arranged in spiral order. This is shown on the stereographic projection, Fig. 155, and also in Figs. 156, 157, which represent the single typical form of the class. These two complementary solids together embrace all the faces of the hexoctahedron. They are distinguished from one another by being called respectively right-handed and left-handed *pentagonal icositetrahedrons*. The other forms of the class are geometrically like those of the normal class.

155

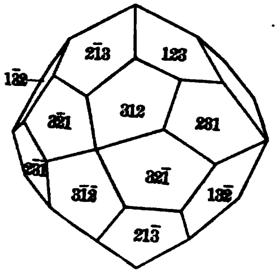


Symmetry of Plagiohedral Class

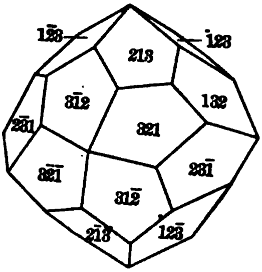
The symmetry characteristic of the class in general is as follows:

There are no planes of symmetry and no center of symmetry. There are, however, three axes of tetragonal symmetry normal to the cubic faces, four axes of trigonal symmetry normal to the octahedral faces, and six axes of binary symmetry normal to the faces of the dodecahedron. In other words, it has all the axes of symmetry of the normal class while without planes or center of symmetry.

156

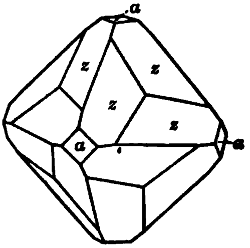


157



Right and Left-handed Pentagonal Icositetrahedrons

158



Cuprite

79. It is to be noted that the two forms shown in Figs. 156, 157 are alike geometrically, but are not superposable; in other words, they are related to one another as is a right- to a left-hand glove. They are hence said to be *enantiomorphous*, and, as explained elsewhere, the crystals belonging here may be expected to show circular light polarization. It will be seen that the complementary positive and negative forms of the preceding classes, unlike those here, may be superposed by being rotated 90° about one of the crystallographic axes. This distinction between positive and negative forms, and between right- and left-handed enantiomorphous forms, exists also in the case of the classes of several of the other systems.

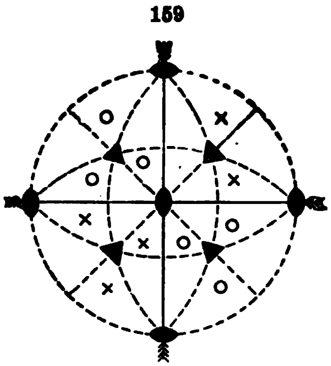
This class is rare among minerals; it is represented by cuprite, sal ammoniac, sylvite, and halite. It is usually shown by the distribution of the small modifying faces, or by the form of the etching figures. Fig. 158 shows a crystal of cuprite from Cornwall (Pratt) with the form $z(13 \cdot 10 \cdot 12)$.

5. TETARTOHEDRAL CLASS (5). ULLMANNITE TYPE.

(*Tetrahedral Pentagonal Dodecahedral Class*)

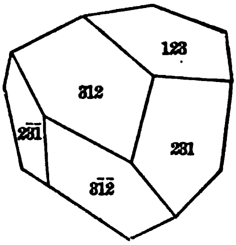
80. Symmetry and Typical Forms. — The fifth remaining possible class under the isometric system is illustrated by Fig. 160, which represents the twelve-faced solid corresponding to the general symbol (*hkl*). The distribution of its faces is shown in the projection, Fig. 159. This form is sometimes called a tetrahedral-pentagonal dodecahedron. It is seen to have one-fourth as many faces as the form (*hkl*) in the normal class, hence there are four similar solids which together embrace all the faces of the hexoctahedron. These four solids, which are distinguished as right-handed (positive and negative) and left-handed (positive and negative), are enantiomorphous, like those of Figs. 156 and 157, and hence the salts crystallizing here may be expected to also show circular polarization. The remaining forms of the class are (besides the cube and rhombic dodecahedron) the tetrahedrons, the pyritohedrons, the tetragonal and trigonal tristetrahedrons; geometrically they are like the solids of the same names already described. This class has no plane of symmetry and no center of symmetry. There are three axes of binary symmetry normal to the cubic faces, and four axes of trigonal symmetry normal to the faces of the tetrahedron.

159

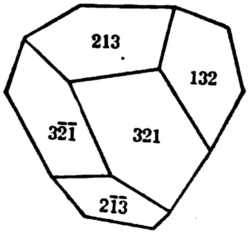


Symmetry of Tetartohedral Class

160



161



This group is illustrated by artificial crystals of barium nitrate, strontium nitrate, sodium chlorate, etc. Further, the species ullmannite, which shows sometimes pyritohedral and again tetrahedral forms, both having the same composition, must be regarded as belonging here.

MATHEMATICAL RELATIONS OF THE ISOMETRIC SYSTEM

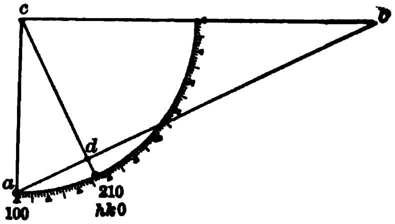
81. Most of the problems arising in the isometric system can be solved at once by the right-angled triangles in the sphere of projection (Fig. 125) without the use of any special formulas.

It will be remembered that the angles between a cubic face, as 100, and the adjacent face of a tetrahexahedron, 310, 210, 320, etc., can be obtained at once, since the tangent of this angle is equal to $\frac{1}{3}, \frac{1}{2}, \frac{2}{3}$, or in general $\frac{k}{h}$

$$\tan (hk0 \wedge 100) = \frac{k}{h}$$

$ac = k = 1$
$bc = h = 2$
$\angle adc = 90°$
$\tan \angle abc = \frac{ac}{bc} = \frac{k}{h} = \frac{1}{2}$
$\left.\begin{array}{c}\angle abc \\ (100) \wedge (210)\end{array}\right\} = 26° 34'$

162



This relation is illustrated in Fig. 162, which also shows the method of graphically determining the indices of a tetrahexahedron, the angle between one of its faces and an adjacent cube face being given.

Since all the forms of a given symbol under different species have the same angles, the tables of angles already given are very useful.

These and similar angles may be calculated immediately from the sphere, or often more simply by the formulas given in the following article.

82. Formulas. — (1) The distance of the pole of any face P(hkl) from the cubic faces is given by the following equations. Here Pa is the distance between (hkl) and (100); Pb is the distance between (hkl) and (010); and Pc that between (hkl) and (001).

These equations admit of much simplification in the various special cases, for ($hk0$), (hhl), etc.:

$$\cos^2 Pa = \frac{h^2}{h^2 + k^2 + l^2}; \quad \cos^2 Pb = \frac{k^2}{h^2 + k^2 + l^2}; \quad \cos^2 Pc = \frac{l^2}{h^2 + k^2 + l^2}$$

(2) The distance between the poles of any two faces P(hkl) and Q(pqr) is given by the following equation, which in special cases may also be more or less simplified:

$$\cos PQ = \frac{hp + kq + lr}{\sqrt{(h^2 + k^2 + l^2)(p^2 + q^2 + r^2)}}.$$

(3) The calculation of the supplement interfacial or normal angles for the several forms may be accomplished as follows:

Trisoctahedron. — The angles A and B are, as before, the supplements of the interfacial angles of the edges lettered as in Fig. 110.

$$\cos A = \frac{h^2 + 2hl}{2h^2 + l^2}; \qquad \cos B = \frac{2h^2 - l^2}{2h^2 + l^2}.$$

For the *tetragonal-tristetrahedron* (Fig. 149), $\cos B = \frac{h^2 - 2hl}{2h^2 + l^2}$.

Trapezohedron (Fig. 113). B and C are the supplement angles of the edges as lettered in the figure.

$$\cos B = \frac{h^2}{h^2 + 2l^2}; \qquad \cos C = \frac{2hl + l^2}{h^2 + 2l^2}.$$

For the *trigonal-tristetrahedron* (Fig. 150), $\cos B = \frac{h^2 - 2l^2}{h^2 + 2l^2}$.

Tetrahexahedron (Fig. 104).

$$\cos A = \frac{h^2}{h^2 + k^2}; \qquad \cos C = \frac{2hk}{h^2 + k^2}.$$

For the *pyritohedron* (Fig. 129), $\cos A = \frac{h^2 - k^2}{h^2 + k^2}$; $\cos C = \frac{hk}{h^2 + k^2}$.

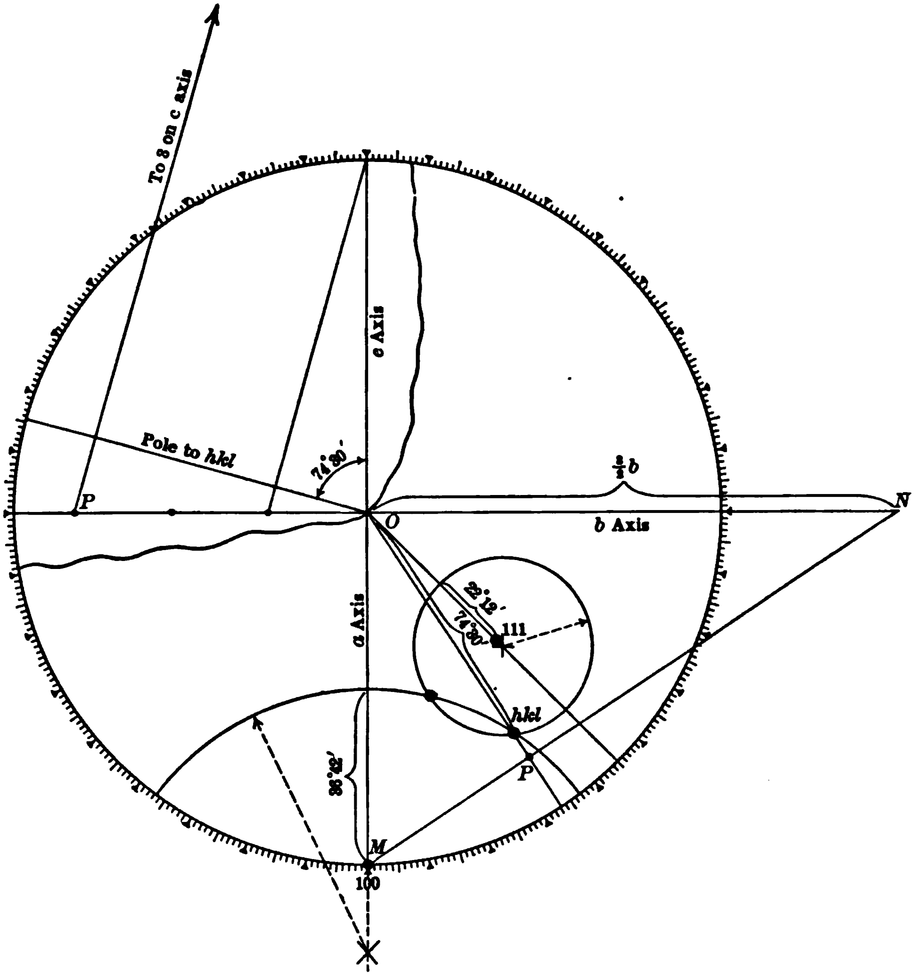
Hexoctahedron (Fig. 122).

$$\cos A = \frac{h^2 + 2kl}{h^2 + k^2 + l^2}; \quad \cos B = \frac{h^2 + k^2 - l^2}{h^2 + k^2 + l^2}; \quad \cos C = \frac{2hk + l^2}{h^2 + k^2 + l^2}.$$

For the *diploid* (Fig. 135), $\cos A = \frac{h^2 - k^2 + l^2}{h^2 + k^2 + l^2}$; $\cos C = \frac{kl + lh + hk}{h^2 + k^2 + l^2}$.

For the *hextetrahedron* (Fig. 151), $\cos B = \frac{h^2 - 2kl}{h^2 + k^2 + l^2}$.

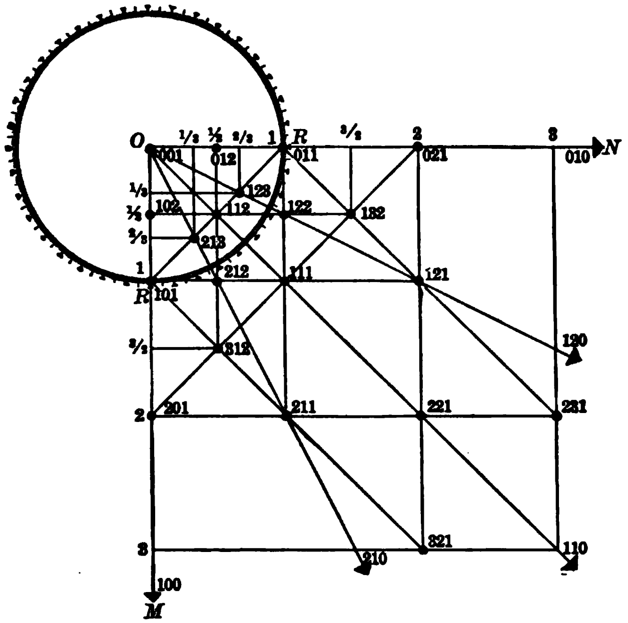
163



83. To determine the indices of any face (*hkl*) of an isometric form, given the position of its pole on the stereographic projection. As an illustrative example of this problem the hexoctahedron (321) has been taken. It is assumed that the angles 100 ∧ 321 = 36° 42′

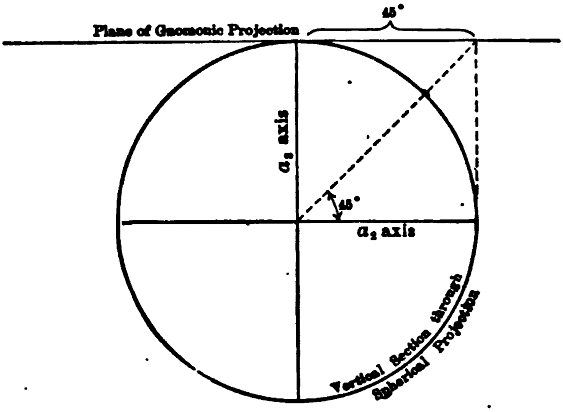
and 111 ∧ 321 = 22° 12′ are given. The methods by which the desired pole is located from these measurements have been described on page 38 and are illustrated in Fig. 163. Having located the pole (*hkl*) a line is drawn through it from the center *O* of the projection. This line *O–P* represents the intersection with the horizontal plane (which is the plane of the horizontal crystal axes, *a* and *b*) of a plane which is normal to the crystal face (*hkl*). Since two planes which are at right angles to each other will intersect a third plane in lines that are at right angles to each other, it follows that the plane of the hexoctahedral face will intersect the plane of the horizontal axes in a line at right angles to *O–P*. If, therefore, the distance *O–M* be taken as representing unity on the *a* axis and the line *M–P–N* be drawn at right angles to *O–P* the distance *O–N* will represent the intercept of the face in question upon the *b* axis. *O–N* is found in this case to be $\frac{3}{2}$ *O–M* in value. The intercepts upon the two horizontal axes are, therefore 1*a*, $\frac{3}{2}$*b*. The plotting of the intercept upon the *c* axis is shown in the upper left hand quadrant of the figure. The angular distance from *O* to the pole (*hkl*) is measured by the stereographic protractor as 74° 30′. This angle is then laid off from the line representing the *c* axis and the line representing the pole (*hkl*) is drawn. The distance *O–P* is transferred from the lower part of the figure. Then we can construct the right triangle, the vertical side of which is the *c* axis, the horizontal side is this line *O–P* (the intersection of the plane which is normal to the crystal face with the horizontal plane) and the hypothenuse is a line lying in the face and therefore at right angles to the pole of the face. This line would intersect the *c* axis at a distance equal to 3*O–M*. The same relation may be shown by starting this last line from a point on the *c* axis which is at a distance from the center of the figure equal to *O–M*. In this case the intercept on the horizontal line *O–P* would be at one third its total length. By these constructions the parameters of the face in question are shown to be 1*a*, $\frac{3}{2}$*b*, 3*c*, giving (321) as its indices.

164



84. To determine the indices of the faces of isometric forms, given the positions of their poles on the gnomonic projection. — As an illustrative example of this problem the lower right hand quadrant of the gnomonic projection of isometric forms, Fig. 126, has been taken and reproduced in Fig. 164. The lines O–M and O–N are at right angles to each other and may represent the horizontal crystallographic axes a_1 and a_2. If from each pole of the projection lines are drawn perpendicular to these two axial directions it will be seen that the intercepts made upon these lines have rational relations to each other. And since we are dealing with the isometric system in which the crystallographic axes are all alike and interchangeable with each other, it follows that the different intercepts upon O–M and O–N are identical. The distance O–R (*i.e.* the distance from the center to the 45° point of the projection) must equal the unit length of the axes. That this is true is readily seen by the consideration of Fig. 165. The intercepts of the lines drawn from the different poles to the lines O–M and O–N are found to be $\frac{1}{3}$, $\frac{1}{2}$, $\frac{2}{3}$, 1, $\frac{3}{2}$, 2 and 3 times this unit distance. To find the Miller indices of any face represented, it is only necessary to take the intercepts of the two lines drawn from its pole upon the two axes a_1 and a_2, place these numbers in their proper order and add a 1 as a third figure and then if necessary clear of fractions. Take for example the hexoctahedron face with indices 312. The lines drawn from its pole intercept the axes at $\frac{3}{2}a_1$ and $\frac{1}{2}a_2$, which gives the expression $\frac{3}{2}$ $\frac{1}{2}$ 1, which, again, on clearing of fractions, yields 312, the indices of the face in question. In the case of a face parallel to the vertical axis, the pole of which lies at infinity on the gnomonic projection, the indices may be obtained by taking any point on the radial line that points to the position of the pole and dropping perpendiculars to the lines representing the two horizontal axes. The relative intercepts formed upon these axes will give the first two numbers of the required indices while the third number will necessarily be 0.

165


45°
Plane of Gnomonic Projection
a_3 axis
45°
a_2 axis
Vertical Section through Spherical Projection

II. TETRAGONAL SYSTEM

85. THE TETRAGONAL SYSTEM includes all the forms which are referred to three axes at right angles to each other of which the two horizontal axes are equal to each other in length and interchangeable and the third, the vertical axis, is either shorter or longer. The horizontal axes are designated by the letter *a*; the vertical axis by *c* (see Fig. 166). The length of the vertical axis expresses properly the axial ratio of *a* : *c*, *a* being uniformly taken as equal to unity. The axes are orientated and their opposite ends designated by plus and minus signs exactly as in the case of the Isometric System.

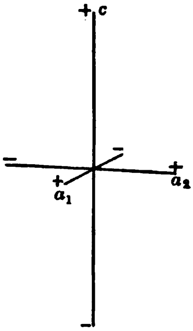
Seven classes are embraced in this system. Of these the normal class is common and important among minerals; two others have several representatives, and another a single one only. It may be noted that in four of the classes the vertical axis is an axis of tetragonal symmetry; in the remaining three it is an axis of binary symmetry only.

1. NORMAL CLASS (6). ZIRCON TYPE

(*Ditetragonal Bipyramidal or Holohedral Class*)

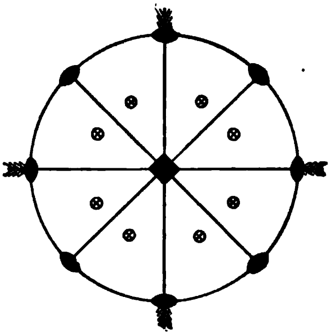
86. Symmetry. — The forms belonging to the normal class of the tetragonal system (cf. Figs. 170 to 192) have one principal axis of tetragonal symmetry (whence name of the system) which coincides with the vertical crystallographic axis, *c*. There are also four horizontal axes of binary symmetry, two of which coincide with the horizontal crystallographic axes while the other two are diagonal axes bisecting the angles between the first two.

166



Axes of Tetragonal Mineral,
Octahedrite $a : c = 1 : 1{\cdot}78$

167



Symmetry of Normal Class
Tetragonal System

Further they have one principal plane of symmetry, the plane of the horizontal crystallographic axes. There are also four vertical planes of symmetry which pass through the vertical crystallographic axis *c* and make angles of 45° with each other. Two of these latter planes include the horizontal crystallographic axes and are known as axial planes of symmetry. The other two are known as diagonal planes of symmetry.

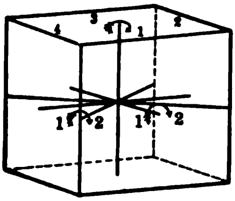
The axes and planes of symmetry are shown in Figs. 168 and 169.

The symmetry and the distribution of the faces of the general form, *hkl*, is shown in the stereographic projection, Fig. 167.

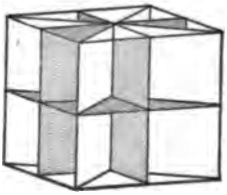
87. Forms. — The various possible forms under the normal class of this system are as follows:

	Symbols
1. Base or basal pinacoid........ .	(001)
2. Prism of the first order.........	(110)
3. Prism of the second order.......	(100)
4. Ditetragonal prism.............	(*hk*0) as, (310); (210); (320), etc.
5. Pyramid of the first order.......	(*hhl*) as, (223); (111); (221), etc.
6. Pyramid of the second order.....	(*h*0*l*) as, (203); (101); (201), etc.
7. Ditetragonal pyramid..........	(*hkl*) as, (421); (321); (122), etc.

168



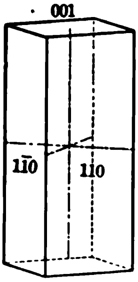
169



Symmetry of Normal Class, Tetragonal System

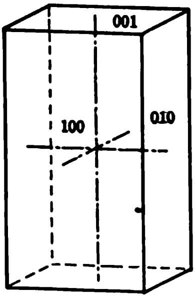
88. Base or Basal Pinacoid. — The *base* is that form which includes the two similar faces which are parallel to the plane of the horizontal axes. These faces have the indices 001 and 00$\bar{1}$ respectively; it is an "open form," as they do not inclose a space, consequently this form can occur only in combination with other forms. Cf. Figs. 170–173, etc. This form is always lettered *c* in this work.

170



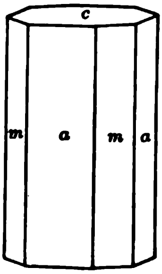
First Order Prism

171



Second Order Prism

172



First and Second Order Prisms

89. Prisms. — Prisms, in systems other than the isometric, have been defined to be forms whose faces are parallel to the vertical axis (*c*) of the crystal, while they meet the two horizontal axes; in this system the four-faced form whose planes are parallel both to the vertical and one horizontal axis is also called a prism. There are hence three types of prisms here included.

90. Prism of First Order. — The *prism of the first order* includes the four faces which, while parallel to the vertical axis, meet the horizontal axes at equal distances; its general symbol is consequently (110). It is a *square prism*, with interfacial angles of 90°. It is shown in combination with the base in Fig. 170. It is uniformly designated by the letter *m*. The indices of its faces, taken in order, are 110, $\bar{1}10$, $\bar{1}\bar{1}0$, $1\bar{1}0$.

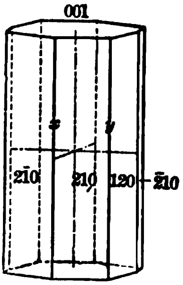
91. Prism of Second Order. — The *prism of the second order* shown* in combination with the base in Fig. 171 includes the four faces which are parallel at once to the vertical and to a horizontal axis; it has, therefore, the general symbol (100). It is a *square prism* with an angle between any two adjacent faces of 90°. It is uniformly designated by the letter *a*, and its faces, taken in order, have the indices 100, 010, $\bar{1}00$, $0\bar{1}0$.

It will be seen that the combination of this form with the base is the analogue of the cube of the isometric system.

The faces of the prism of the first order truncate the edges of the prism of the second order and *vice versa*. When both are equally developed, as in Fig. 172, the result is a regular eight-sided prism, which, however, it must be remembered, is a combination of *two* distinct forms.

It is evident that the two prisms described do not differ geometrically from one another, and furthermore, in a given case, the symmetry of this class allows either to be made the first order, and the other the second order, prism according to the position assumed for the horizontal axes. If on crystals of a given species both forms occur together equally developed (or, on the other hand, separately on different crystals) and without other faces than the base, there is no means of telling them apart unless by minor characteristics, such as striations or other markings on the surface, etchings, etc.

173



Ditetragonal Prism

92. Ditetragonal Prism. — The *ditetragonal prism* is the form which is bounded by eight similar faces, each one of which is parallel to the vertical axis while meeting the two horizontal axes at unequal distances. It has the general symbol (*hk*0). It is shown in Fig. 173, where (*hk*0) = (210). The successive faces have here the indices 210, 120, $\bar{1}20$, $\bar{2}10$, $\bar{2}\bar{1}0$, $\bar{1}\bar{2}0$, $1\bar{2}0$, $2\bar{1}0$.

In Fig. 185 a combination is shown of this form (*y* = 310) with the second order prism, the edges of which it bevels. In Fig. 189 (*h* = 210) it bevels the edges of the first order prism *m*. In Fig. 190 (*l* = 310) it is combined with both orders of prisms.

93. Pyramids. — There are three types of pyramids in this class, corresponding, respectively, to the three prisms which have just been described.

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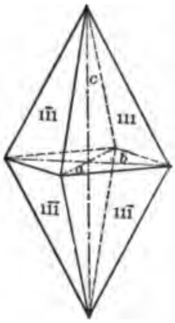
* In Figs. 170–173 the dimensions of the form are made to correspond to the assumed length of the vertical axis (here c = 1·78 as in octahedrite) used in Fig. 177. It must be noted, however, that in the case of actual crystals of these forms, while the tetragonal symmetry is usually indicated by the unlike physical character of the face c as compared with the faces a, m, etc., in the vertical prismatic zone, no inference can be drawn as to the relative length of the vertical axis. This last can be determined only when a pyramid is present; it is fixed for the species when a particular pyramid is chosen as fundamental or unit form, as explained later.

As already stated, the name *pyramid* is given (in systems other than the isometric) to a form whose planes meet all three of the axes; in this system the form whose planes meet the axis *c* and one horizontal axis while parallel to the other is also called a pyramid. The pyramids of this class are strictly double pyramids (*bipyramids* of some authors).

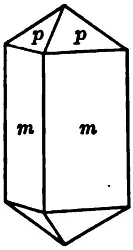
94. Pyramid of First Order. — A *pyramid of the first order*, is a form whose eight similar faces intersect the two horizontal axes at equal distances and also intersect the vertical axis. It has the general symbol (*hhl*). It is a *square pyramid* with equal interfacial angles over the terminal edges, and the faces replace the horizontal, or basal, edges of the first order prism and the solid angles of the second order prism. If the ratio of the vertical to the horizontal axis for a given first order pyramid is the assumed axial ratio for the species, the form is called the *fundamental form*, and it has the symbol (111) as in Fig. 174. The indices of its faces mentioned in order are: Above 111, $\bar{1}11$, $\bar{1}\bar{1}1$, $1\bar{1}1$; below $11\bar{1}$, $\bar{1}1\bar{1}$, $\bar{1}\bar{1}\bar{1}$, $1\bar{1}\bar{1}$.

174



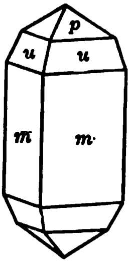
First Order Pyramid

175



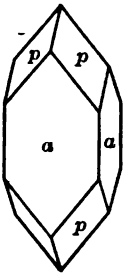
Zircon, First Order Prism and Pryamid

176



Zircon, First Order Prism and Pyramids

177



Apophyllite, Second Order Prism and First Order Pyramid

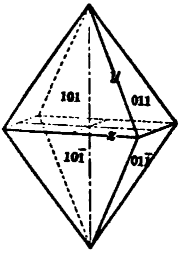
Obviously the angles of the first order pyramid, and hence its geometrical aspect, vary widely with the length of the vertical axis. In Figs. 174 and 182 the pyramids shown have in both cases the symbol (111) but in the first case (octahedrite) $c = 1.78$, while in the second (vesuvianite), $c = 0.64$.

For a given species there may be a number of second order pyramids, varying in position according to the ratio of the intercepts upon the vertical and horizontal axes. Their symbols, passing from the base (001) to the unit prism (110), may thus be (115), (113), (223), (111), (332), (221), (441), etc. In the general symbol of these forms (*hhl*), as *h* diminishes, the form approximates more and more nearly to the base (001), for which $h = 0$; as *h* increases, the form passes toward the first order prism. In Fig. 176 two pyramids of this order are shown, *p*(111) and *u*(331).

95. Pyramid of Second Order. — The *pyramid of the second order* is the form, Fig. 178, whose faces are parallel to one of the horizontal axes, while meeting the other two axes. The general symbol is (*h0l*). These faces replace the basal edges of the second order prism (Fig. 179), and the solid angles of the first order prism (cf. Fig. 180). It is a *square pyramid* since its basal section is a square, and the interfacial angles over the four terminal edges, above and below, are equal. The successive faces of the form (101) are as follows: Above 101, 011, $\bar{1}01$, $0\bar{1}1$; below $10\bar{1}$, $01\bar{1}$, $\bar{1}0\bar{1}$, $0\bar{1}\bar{1}$.

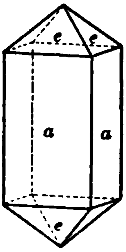
If the ratio of the intercepts on the horizontal and vertical axes is the assumed axial ratio of the species, the symbol is (101), and the form is designated by the letter *e*. This ratio can be deduced from the measurement of either one of the interfacial angles (*y* or *z*, Fig. 178) over the terminal or basal edges, as explained later. In the case of a given species, a number of second order pyramids may occur, varying in the ratio of the axes *a* and *c*. Hence there is possible a large number of such forms whose symbols may be, for example, (104), (103), (102), (101), (302), (201), (301), etc. Those mentioned first come nearest to the base (001), those last to the second order prism (100); the base is therefore the limit of these pyramids (*h*0*l*) when *h* = 0, and the second order prism (100) when *h* = 1 and *l* = 0. Fig. 186 shows the three second order pyramids *u*(105), *e*(101), *q*(201).

178



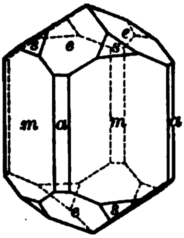
Second Order Pyramid

179



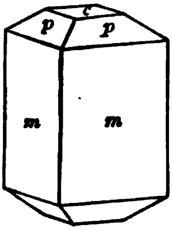
Second Order Prism and Pyramid

180



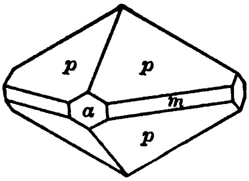
Rutile, First and Second Order Prisms and Pyramids

181



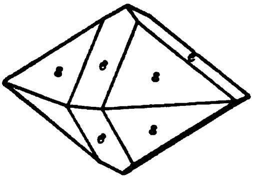
Vesuvianite
First Order Prism,
Pyramid and Base

182



Vesuvianite
First Order Pyramid and
First and Scond Order
Prisms

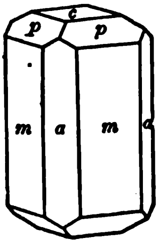
183



Cassiterite
First and Second Order
Pyramids

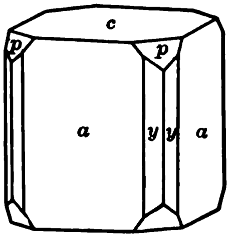
A second order pyramid truncating the pyramidal edges of a given first order pyramid as in Fig. 183 has the *same* ratio as it for *h* to *l*. Thus (101) truncates the terminal edge of (111); (201) of (221), etc. This is obvious because each face has the same position as the corresponding edge of the other form (see Fig. 183, when *s* = 111 and *e* = 101; also Figs. 186, 191, where *r* = 115, *u* = 105). Again, if a first order pyramid truncates the pyramidal edges of a given second order pyramid, its ratio for *h* to *l* is *half* that of the other form; that is, (112) truncates the pyramidal edges of (101); (111) of (201), etc. This relation is exhibited by Fig. 186, where *p*(111) truncates the edges of *q*(201). In both cases the zonal equations prove the relations stated.

184



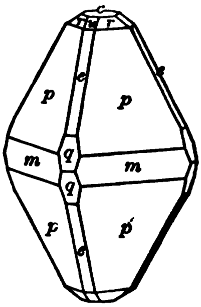
Vesuvianite
First and Second Order Prisms, First Order Pyramid and Base

185



Apophyllite
Second Order Prism, Ditetragonal Prism, First Order Pyramid and Base

186

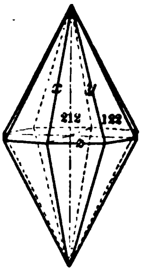


Octahedrite
Two First Order Pyramids, First Order Prism, Three Second Order Pyramids and Base

96. Ditetragonal Pyramid. — The *ditetragonal pyramid*, or double eight-sided pyramid, is the form each of whose sixteen similar faces meets the three axes at unequal distances. This is the most general case of the symbol (*hkl*), where *h*, *k*, *l* are all unequal and no one is equal to 0. That there are sixteen faces in a single form is evident. Thus, for example, for the form (212) the face 212 is similar to 122, the two lateral axes being equal (not, however, to 221). Hence there are two like faces in each octant. Similarly the indices of all the faces in the successive octants are, therefore, as follows:

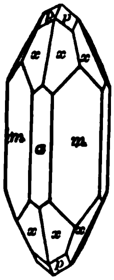
Above	212	122	$\bar{1}22$	$\bar{2}12$	$\bar{2}\bar{1}2$	$\bar{1}\bar{2}2$	$1\bar{2}2$	$2\bar{1}2$
Below	$21\bar{2}$	$12\bar{2}$	$\bar{1}2\bar{2}$	$\bar{2}1\bar{2}$	$\bar{2}\bar{1}\bar{2}$	$\bar{1}\bar{2}\bar{2}$	$1\bar{2}\bar{2}$	$2\bar{1}\bar{2}$

187



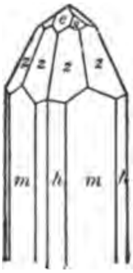
Ditetragonal Pyramid

188



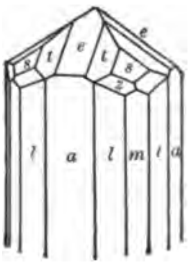
Zircon
First and Second Order Prisms, First Order Pyramid, Ditetragonal Pyramid

189



Cassiterite

190

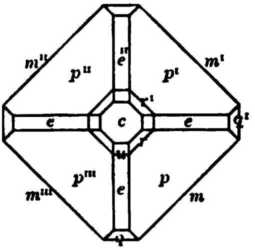


Rutile

This form is common with the species zircon, and is hence often called a *zirconoid*. It is shown in Fig. 187. It is not observed alone, though sometimes, as in Figs. 188 ($x = 311$) and 189 ($z = 321$), it is the predominating form. In Fig. 190 two ditetragonal pyramids occur, namely, $t(313)$ and $z(321)$.

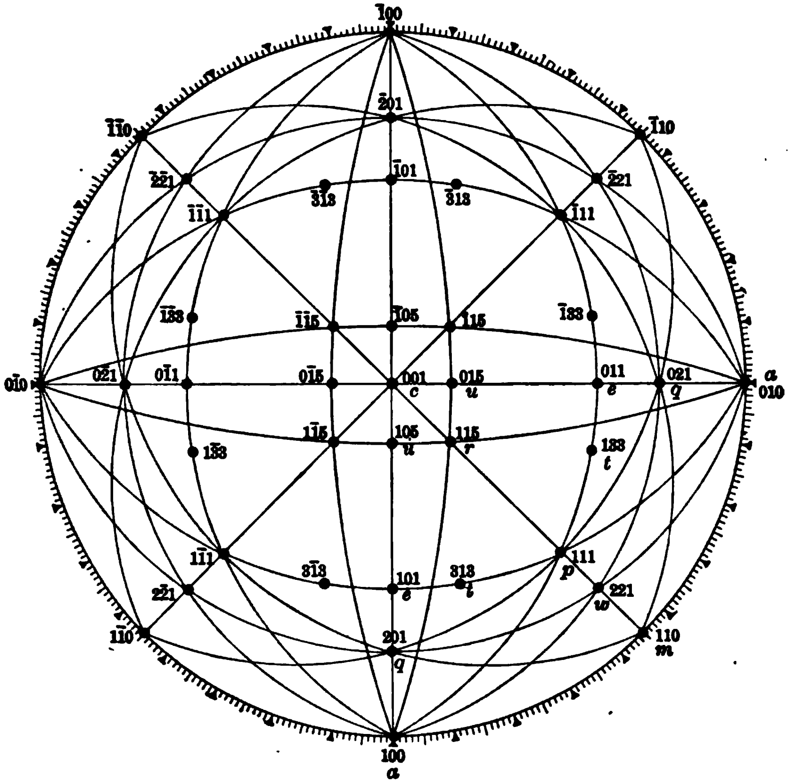
97. In addition to the perspective figures already given, a basal projection (Fig. 191) is added of the crystal of octahedrite already referred to (Fig. 186); also a stereographic (Fig. 192) and gnomonic (Fig. 193) projections of the same with the faces of the forms $w(221)$ and $t(313)$ added. These exhibit well the general relations of this normal class of the tetragonal system. The symmetry here is to be noted, first, with respect to the similar zones 100, 001, $\bar{1}00$ and 010, 001, $0\bar{1}0$; also, to the other pair of similar zones, 110, 001, $\bar{1}\bar{1}0$, and $1\bar{1}0$, 001, $\bar{1}10$.

191



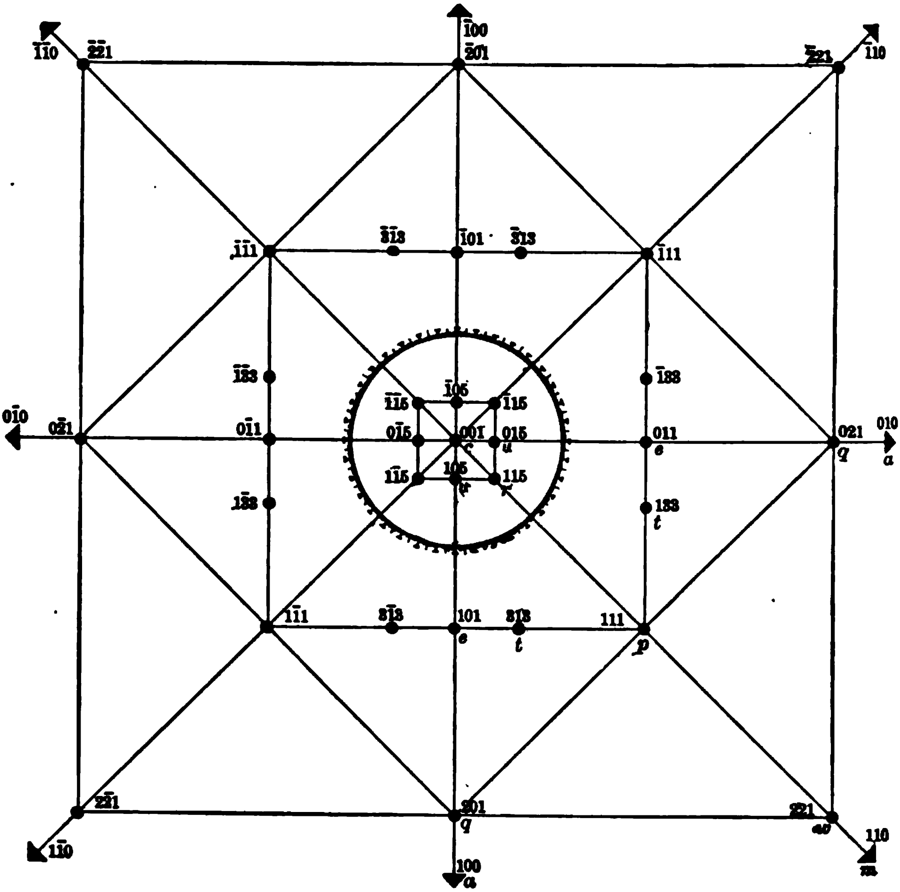
Octahedrite

192



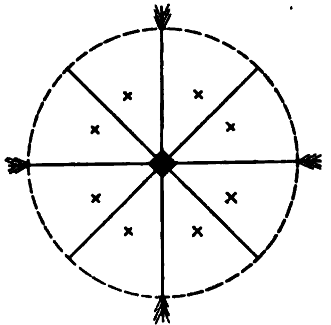
Stereographic Projection of Octahedrite

193



Gnomonic Projection of Octahedrite

194



Symmetry of Hemimorphic Class

2. HEMIMORPHIC CLASS (7). IODOSUCCINIMIDE TYPE

(*Ditetragonal Pyramidal or Holohedral Hemimorphic Class*)

98. Symmetry. — This class differs from the normal class only in having no horizontal plane of symmetry; hence the forms are hemimorphic as defined in Art. **29.** It is not known to be represented among minerals, but is shown on the crystals of iodosuccinimide. Its symmetry is illustrated by the stereographic projection (Fig. 194). Here the two basal planes are distinct forms, 001 and 00$\bar{1}$; the prisms do not differ geometrically from those of the normal class, though distinguished by their molecular structure; further, the pyramids are no longer double pyramids, but each form is represented by one half of Figs. 174, 178, 187 (cf. Fig. 44, p. 22). There are hence six distinct pyramidal forms, corresponding to the upper and lower halves of the first and second order pyramids and the ditetragonal pyramid.

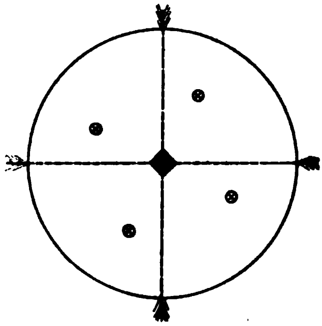
3. TRIPYRAMIDAL CLASS (8). SCHEELITE TYPE.

(*Tetragonal Bipyramidal or Pyramidal Hemihedral Class*)

99. Typical Forms and Symmetry. — The forms here included have one plane of symmetry only, that of the horizontal crystallographic axes, and one axis of tetragonal symmetry (the vertical crystallographic axis) normal to it. The distinctive forms are the tetragonal prism (*hk*0) and pyramid (*hkl*) of the *third order*, shown in Figs. 196, 197.

The stereographic projection, Fig. 195, exhibits the symmetry of the class and the distribution of the faces of the general form (*hkl*). Comparing this, as well as the figures immediately following, with those of the normal class, it is seen that this class differs from it in the absence of the vertical planes of symmetry and the horizontal axes of symmetry.

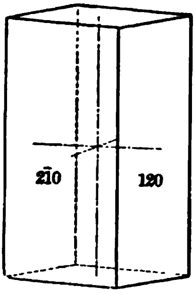
195



Symmetry of Tri-Pyramidal Class

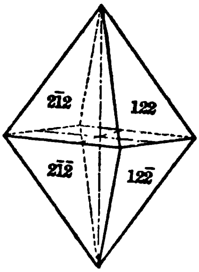
100. Prism and Pyramid of the Third Order. — The typical forms of the class, as above stated, are a square prism and a square pyramid, which are distinguished respectively from the square prisms *a*(100) and *m*(110), shown in Figs. 170 and 171, and from the square pyramids (*h*0*l*) and (*hhl*) of Figs. 174 and 178 by the name "*third order.*"

196



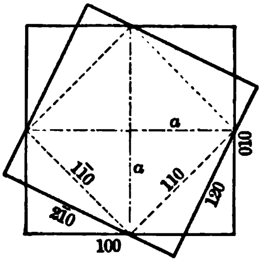
Third Order Prism

197



Third Order Pyramid

198



The third order prism and pyramid may be considered as derived from the ditetragonal forms of the normal class by taking only one half the faces of the latter and the omission of the remaining faces. There are therefore two complementary forms in each case, designated *left* and *right*, which together include all the faces of the ditetragonal prism (Fig. 173) and ditetragonal pyramid (Fig. 187) of the normal class.

The indices of the faces of the two complementary prisms, as (210), are:

Left: 210, $\bar{1}20$, $\bar{2}\bar{1}0$, $1\bar{2}0$.
Right: 120, $\bar{2}10$, $\bar{1}\bar{2}0$, $2\bar{1}0$.

The indices of the faces of the corresponding pyramids, as (212), are:

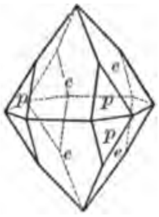
Left: above 212, $\bar{1}22$, $\bar{2}\bar{1}2$, $1\bar{2}2$; below $21\bar{2}$, $\bar{1}2\bar{2}$, $\bar{2}\bar{1}\bar{2}$, $1\bar{2}\bar{2}$.
Right: above 122, $\bar{2}12$, $\bar{1}\bar{2}2$, $2\bar{1}2$; below $12\bar{2}$, $\bar{2}1\bar{2}$, $\bar{1}\bar{2}\bar{2}$, $2\bar{1}\bar{2}$.

Fig. 198 gives a transverse section of the prisms $a(100)$ and $m(110)$, also the prism of the third order (120). Figs. 196, 197 show the right prism (120) and pyramid (122) of the third order.

101. Other Forms. — The other forms of this class, that is, the base $c(001)$; the other square prisms, $a(100)$ and $m(110)$; also the square pyramids $(h0l)$ and (hhl) are geometrically like the corresponding forms of the normal class already described. The class shows therefore three types of square pyramids and hence is called the *tripyramidal class.*

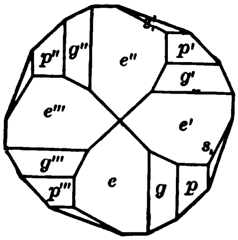
102. To this class belongs the important species scheelite; also the isomorphous species stolzite and powellite, unless it be that they are rather to be classed with wulfenite (p. 87). Fig. 199 shows a typical crystal of scheelite, and Fig. 200 a basal section of one similar; these illustrate well the characteristics of the class. Here the forms are $e(101)$, $p(111)$, and the third-order pyramids $g(212)$, $s,(131)$. Fig. 201 represents a meionite crystal with $r(111)$, and the third-order pyramid $z(311)$. See also Figs. 203, 204, in which the third-order prism is shown.

199



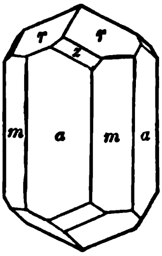
Scheelite

200



Scheelite

201



Meionite

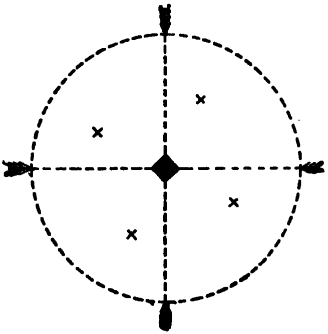
The forms of this class are sometimes described (see Art. 28) as showing *pyramidal hemihedrism.*

4. PYRAMIDAL-HEMIMORPHIC CLASS (9). WULFENITE TYPE

(*Tetragonal Pyramidal or Hemihedral Hemimorphic Class*)

103. Symmetry. — The fourth class of the tetragonal system is closely related to the class just described. It has the same vertical axis of tetragonal symmetry, but there is no horizontal plane of symmetry. The forms are, therefore, hemimorphic in the distribution of the faces (cf. Fig. 202). The species wulfenite of the Scheelite Group among mineral species probably belongs here, although the crystals do not always show the difference between the pyramidal faces, above and below, which would characterize distinct complementary forms. Figs. 203, 204 could, therefore, serve as illustrations of the preceding class, but in Fig. 205 a characteristic distinction is exhibited. In these figures the forms are *u*(102), *e*(101), *n*(111); also *f*(230), *k*(210). *z*(432), *x*(311).

202



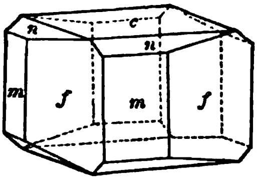
Symmetry of Pyramidal-Hemimorphic Class

5. SPHENOIDAL CLASS (10). CHALCOPYRITE TYPE

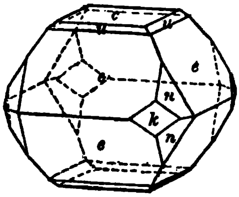
(Tetragonal Sphenoidal, Sphenoidal Hemihedral or Scalenohedral Class)

104. Typical Forms and Symmetry. — The typical forms of this class are the sphenoid (Fig. 207) and the tetragonal scalenohedron (Fig. 208). They and all the combinations of this class show the following symmetry. The three crystallographic axes are axes of binary symmetry and there are two vertical diagonal planes of symmetry.

203

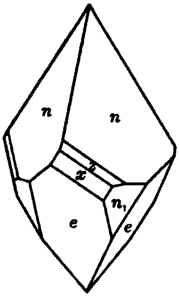


204

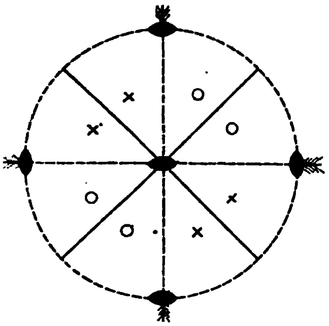


Wulfenite

205



206

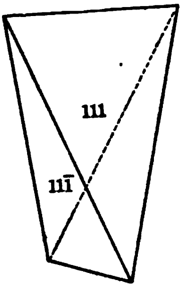


Symmetry of Sphenoidal Class

This symmetry is exhibited in the stereographic projection (Fig. 206), which shows also the distribution of the faces of the general form (*hkl*). It is seen here that the faces are present in the alternate octants only, and it will be remembered that this same statement was made of the tetrahedral class under the isometric system. There is hence a close analogy between these two classes. The symmetry of this class should be carefully compared with that of the first and third classes of this system already described.

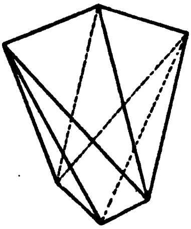
105. Sphenoid. — The *sphenoid*, shown in Fig. 207, is a four-faced solid, resembling a tetrahedron, but each face is an isosceles (not an equilateral) triangle. It may be considered as derived from the first order pyramid of the normal class by the development of only the alternate faces of the latter. There are therefore possible two complementary forms known as the positive and negative sphenoids. The general symbol of the positive unit sphenoid is (111), and its faces have the indices: 111, $\bar{1}\bar{1}1$, $\bar{1}1\bar{1}$, $1\bar{1}\bar{1}$, while the negative sphenoid has the symbol ($1\bar{1}1$). When the complementary forms occur together, if equally developed, the resulting solid, though having two unlike sets of faces, cannot be distinguished geometrically from the first order pyramid (111).

207



Sphenoid

208

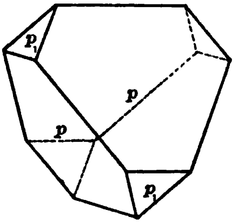


Tetragonal Scalenohedron

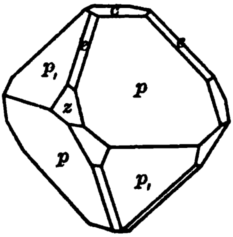
In the species chalcopyrite, which belongs to this class, the deviation in angle and in axial ratio from the isometric system is very small, and hence the unit sphenoid cannot by the eye be distinguished from a tetrahedron (compare Fig. 209 with Fig. 144, p. 68). For this species $c = 0{\cdot}985$ (instead of 1, as in the isometric system), and the normal sphenoidal angle is 108° 40′, instead of 109° 28′, the angle of the tetrahedron. Hence a crystal of chalcopyrite with both the positive and negative sphenoids equally developed closely resembles a regular octahedron.

In Fig. 210 the second order pyramids *e*(101) and *z*(201) and base *c*(001) are also present.

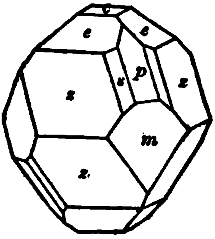
209



210



211



Chalcopyrite

106. Tetragonal Scalenohedron. — The sphenoidal symmetry yields another distinct type of form, that shown in Fig. 208. It is bounded by eight similar scalene triangles, and hence is called a *tetragonal scalenohedron;* the general symbol is (*hkl*). It may be considered as derived from the ditetragonal pyramid of the normal class by taking the alternate *pairs* of faces of the latter form. The faces of the complementary positive and negative forms therefore embrace all the faces of the ditetragonal pyramid. This form appears in combination in chalcopyrite, but is not observed independently. In Fig. 211 the form *s*(531) is the positive tetragonal scalenohedron.

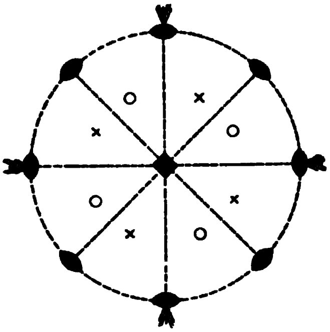
107. Other Forms. — The other forms of the class, namely, the first and second order prisms, the ditetragonal prism, and the first and second order pyramids (*hhl*) and (*h0l*), are geometrically like those of the normal class. The lower symmetry in the molecular structure is onlv revealed by special investigation, as by etching.

6. TRAPEZOHEDRAL CLASS (11). NICKEL SULPHATE TYPE

(*Tetragonal Trapezohedral or Trapezohedral Hemihedral Class*)

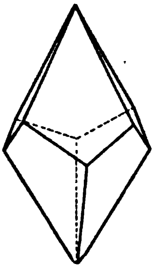
108. The trapezohedral class is analogous to the plagiohedral class under the isometric system; it is characterized by the absence of any plane or center of symmetry; the vertical axis, however, is an axis of tetragonal symmetry, and perpendicular to this there are four axes of binary symmetry. This symmetry and the distribution of the faces of the general form (*hkl*) are shown in the stereographic projection, Fig. 212, and Fig. 213 gives the resulting solid, a *tetragonal trapezohedron*. It may be derived from the ditetragonal pyramid of the normal class by the extension of the alternate faces of that form. There are two complementary forms called right- and left-handed which embrace all the faces of the ditetragonal pyramid of the normal class. These two forms are enantiomorphous, and the salts belonging to this class show circular polarization.

212



Symmetry of Trapezohedral Class

213



Tetragonal Trapezohedron

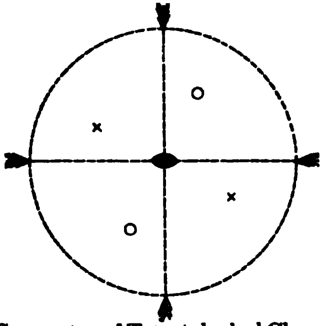
Nickel sulphate and a few other artificial salts belong in this class.

7. TETARTOHEDRAL CLASS (12)

(*Tetragonal Bisphenoidal or Sphenoidal Tetartohedral Class*)

109. Symmetry. — The seventh and last possible class under this system has no plane nor center of symmetry, but the vertical axis is an axis of binary symmetry. The symmetry and the distribution of the faces of the general form (*hkl*) are shown in the stereographic projection (Fig. 214), and the solid resulting is known as a *sphenoid of the third order.* It can be derived from the ditetragonal pyramid of the normal class by taking only one quarter of the faces of that form. There are therefore four complementary forms which are respectively distinguished as right (+ and −) and left (+ and −). These four together embrace all the sixteen faces of the ditetragonal pyramid. The other characteristic forms of this class are the prism of the third order (*hk*0), the positive and negative sphenoids of the first order (111), and also those of the second order (101). It is said that an artificial compound, $2CaO.Al_2O_3.SiO_2$, crystallizes in this class.

214



Symmetry of Tetartohedral Class

Mathematical Relations of the Tetragonal System

110. Choice of Axes. — It appears from the discussion of the symmetry of the seven classes of this system that with all of them the position of the vertical axis is fixed. In classes 1, 2, however, where there are two sets of vertical planes of symmetry, either set may be made the axial planes and the other the diagonal planes. The choice between these two possible positions of the horizontal axes is guided particularly by the habit of the occurring crystals and the relations of the given species to others of similar form. With a species whose crystal characters have been described it is customary to follow the orientation given in the original description.

111. Determination of the Axial Ratio, etc. — The following relations serve to connect the axial ratio, that is, the length of the vertical axis *c*, when $a = 1$, with the fundamental angles (001 ∧ 101) and (001 ∧ 111):

$$\tan (001 \wedge 101) = c; \qquad \tan (001 \wedge 111) \times \tfrac{1}{2}\sqrt{2} = c.$$

For faces in the same rectangular zone the tangent principle applies. The most important cases (cf. Fig. 214) are:

$$\frac{\tan (001 \wedge h0l)}{\tan (001 \wedge 101)} = \frac{h}{l};$$

$$\frac{\tan (001 \wedge 0kl)}{\tan (001 \wedge 011)} = \frac{k}{l};$$

$$\frac{\tan (001 \wedge hhl)}{\tan (001 \wedge 111)} = \frac{h}{l}.$$

For the prisms

$$\tan (010 \wedge hk0) = \frac{h}{k}, \qquad \text{or} \qquad \tan (100 \wedge hk0) = \frac{k}{h}.$$

112. Other Calculations. — It will be noted that in the stereographic projection (Fig. 214) all those spherical triangles are right-angled which are formed by great circles (diameters) which meet the prismatic zone-circle 100, 010, $\bar{1}00$, $0\bar{1}0$. Again, all those formed by great circles drawn between 100 and $\bar{1}00$, or 010 and $0\bar{1}0$, and crossing respectively the zone-circles 100, 001, $\bar{1}00$, or 010, 001, $0\bar{1}0$. Also, all those formed by great circles drawn between 110 and $\bar{1}\bar{1}0$ and crossing the zone-circle $\bar{1}10$, 001, $1\bar{1}0$, or between $\bar{1}10$ and $1\bar{1}0$ and crossing the zone-circle 110, 001, $\bar{1}\bar{1}0$.

These spherical triangles may hence be readily used to calculate any angles desired; for example, the angles between the pole of any face, as *hkl* (say 321), and the pinacoids 100, 010, 001. The terminal angles (*x* and *z*, Fig. 187) of the ditetragonal pyramid, 212 ∧ $2\bar{1}2$ (or 313 ∧ $3\bar{1}3$, etc.), and 212 ∧ 122 (or 313 ∧ 133, etc.), can also be obtained in the same way. The zonal relations give the symbols of the poles on the zones 001, 100 and 001, 110 for the given case. For example, the zone-circle $1\bar{1}0$, 313, 133, $\bar{1}10$ meets $\bar{1}\bar{1}0$, 001, 110 at the pole 223, and the calculated angle 313 ∧ 223 is half the angle 313 ∧ 133. If a large number of similar angles are to be calculated, it is more convenient to use a formula, as that given below

113. Formulas. — It is sometimes convenient to have the normal interfacial angles expressed directly in terms of the axis *c* and the indices *h*, *k*, and *l*. Thus:

(1) The distances of the pole of any face P(*hkl*) from the pinacoids *a*(100) = P*a*, *b*(010) = P*b*, *c*(001) = P*c* are given by the following equations:

$$\cos^2 \mathrm{P}a = \frac{h^2c^2}{h^2c^2 + k^2c^2 + l^2}; \quad \cos^2 \mathrm{P}b = \frac{k^2c^2}{h^2c^2 + k^2c^2 + l^2}; \quad \cos^2 \mathrm{P}c = \frac{l^2}{h^2c^2 + k^2c^2 + l^2}$$

These may also be expressed in the form

$$\tan^2 \mathrm{P}a = \frac{k^2c^2 + l^2}{h^2c^2}; \quad \tan^2 \mathrm{P}b = \frac{h^2c^2 + l^2}{k^2c^2}; \quad \tan^2 \mathrm{P}c = \frac{h^2c^2 + k^2c^2}{l^2}.$$

(2) For the distance between the poles of any two faces (*hkl*), (*pqr*), we have in general

$$\cos \mathrm{PQ} = \frac{hpc^2 + kqc^2 + lr}{\sqrt{[(h^2 + k^2)c^2 + l^2]\,[(p^2 + q^2)c^2 + r^2]}}.$$

The above equations take a simpler form for special cases often occurring; for example, for *hkl* and the angle of the edge *y* of Fig. 187.

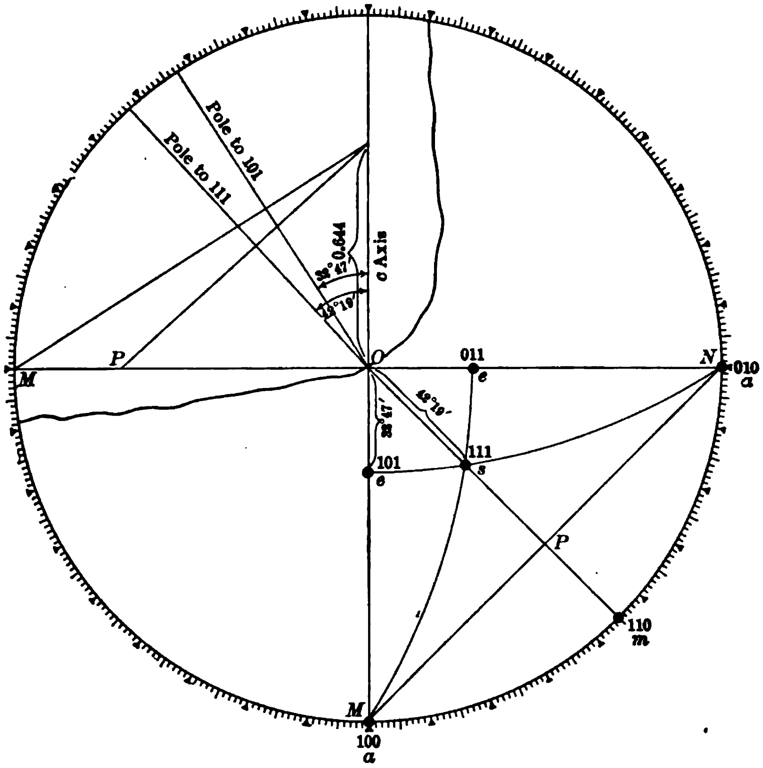
114. Prismatic Angles. — The angles for the commonly occurring ditetragonal prisms are as follows·

	Angle on *a*(100)	Angle on *m*(110)		Angle on *a*(100)	Angle on *m*(110)
410	14° 2¼′	30° 57¾′	530	30° 57¾′	14° 2¼′
310	18 26	26 34	320	33 41¼	11 18¾
210	26 34	18 26	430	36 52¼	8 7¾

115. To determine, by plotting, the axial ratio, *a* : *c*, of a tetragonal mineral from the stereographic projection of its crystal forms. As an illustrative example it has been assumed that the angles between the faces on the crystal of rutile, represented in Fig 180, have been measured and from these measurements the poles of the faces in one octant located on the stereographic projection, see Fig. 215. In determining the axial ratio of a tetragonal crystal (or what is the same thing, the length of the *c* axis, since the length of the *a* axes are always taken as equal to 1) it is necessary to assume the indices of some pyramidal form. It is customary to take a pyramid which is prominent upon the crystals of the mineral and assume that it is the fundamental or unit pyramid of either the first or second order and has as its symbol either (111) or (101). In the example chosen both a first order and a second order pyramid are present and from their zonal relations it is evident that if the symbol assigned to the first order form be (111) that of the second order form must be (101), In order to determine the relative length of the *c* axis in respect to the length of the *a* axis for rutile therefore, it is only necessary to plot the intercept of either of these forms upon the axes. In the case of the second order pyramid it is only necessary to construct a right angle triangle (see upper left hand quadrant of Fig. 215) in which the horizontal side shall equal the length of the *a* axis, (1), the vertical side shall represent the *c* axis and the hypothenuse shall show the proper angle of slope of the face. The angle between the center of the projection and the pole *e*(101) is measured by the stereographic protractor and a line drawn making that angle with the line representing the *c* axis. The hypothenuse of the triangle must then be at right angles to this pole. Its intercept upon the vertical side of the triangle, when expressed in relation to the distance (*O–M*) which was chosen as representing unity on the *a* axis, will therefore give the length of the *c* axis. In rutile this is found to be 0.644.

The same value is obtained when the position of the pyramid of the first order *s*(111) is used. In this case the line *M–P–N* is first drawn at right angles to the radial line *O–P* drawn through the pole *s*(111). The triangle to be plotted in this case has the distance *O–P* as the length of its horizontal side. Its hypothenuse must be at right angles to the line representing the pole to (111). The intercept on the *c* axis is the same as in the first case.

215


Pole to 101
Pole to 111
32°47'
0.644
c Axis
42°19'
O
P
M
011
e
N
010
a
42°19'
32°47'
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M
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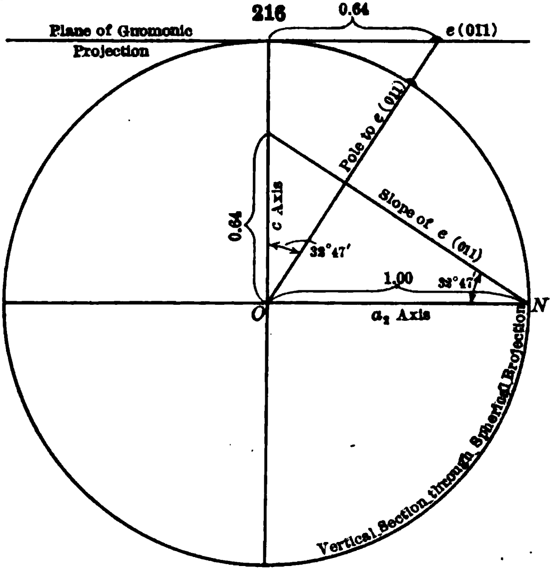
a

216


0.64
Plane of Gnomonic Projection
e (011)
Pole to e (011)
Slope of e (011)
c Axis
0.64
32°47'
1.00
32°47'
O
N
a_2 Axis
Vertical Section through Spherical Projection

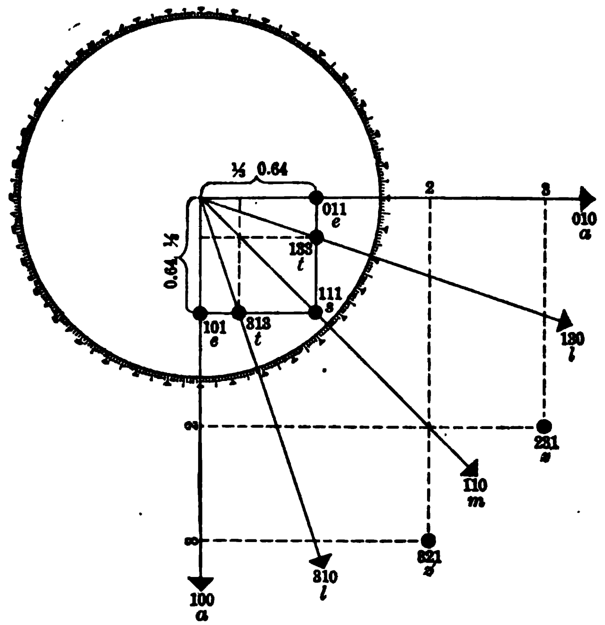
116. To determine, by plotting, the indices of any face (*hkl*) of a tetragonal form from the position of its pole on the stereographic projection. The solution of this problem is like that given in a similar case under the Isometric System, see p. 74, except that the intercept of the face on the vertical axis must be referred to the established unit length of that axis and not to the length of the *a* axis. The method is exactly the reverse of the one used in the problem discussed directly above.

117. To determine, by plotting, the axial ratio, *a* : *c*, of a tetragonal mineral from the gnomonic projection of its crystal forms. As an illustrative example consider the crystal of rutile, Fig. 180, the poles to the faces of which, are shown plotted in gnomonic projection in Fig. 216. The pyramids of the first and second order present are taken as the unit forms with the symbols, *s*(111) and *e*(101). The lines O–M and O–N represent the two horizontal axes a_1 and a_2 and the distance from the center O to the circumference of the fundamental circle is equal to unity on these axes. The intercepts on O–M and O–N made by the poles of *e*(101) or the perpendiculars drawn from the poles of *s*(111) give the unit length of the vertical axis, *c*. In this case this distance, when expressed in terms of the assumed length of the horizontal axes (which in the tetragonal system always equals 1) is equal to 0.64.

That the above relation is true is obvious from a consideration of Fig. 216. This represents a vertical section through the spherical and gnomonic projection including the horizontal axis, a_2. The slope of the face *e*(011) is plotted with its intercepts on the a_2 and *c* axes and the position of its pole in both the spherical and gnomonic projections is shown. It is seen through the two similar triangles in the figure that the distance from the center to the pole *e*(011) in the gnomonic projection must be the same as the intercept of the face *e* upon the vertical axis *c*. And as *e* is a unit form this must represent unity on *c*.

118. To determine, by plotting, the indices of any face of a tetragonal form from the position of its pole on the gnomonic projection. It is assumed that in this case a mineral is being considered whose axial ratio is known. Under these conditions draw perpendiculars from the pole in question to the lines representing the two horizontal axes. Then space off on these lines distances equivalent to the length of the *c* axis, remembering that it must be expressed in terms of the length of the horizontal axes which in turn is equal to the distance from the center of the projection to the circumference of the fundamental circle. Give the intercepts of the lines drawn from the pole of the face to the axes a_1 and a_2 in terms of the length of the vertical axis, add a 1 as the third figure and if necessary clear of fractions and the required indices are the result. This is illustrated in Fig. 217, which is the lower right hand quadrant of the gnomonic projection of the forms shown on the rutile crystal, Fig. 190. Consider first the ditetragonal pyramid *z*(321). Perpendiculars drawn from its pole intersect the lines representing the horizontal axes in distances which are equal to 3 and 2 times the unit length of the *c* axis, 0.64. The indices of the face will therefore be 321. In the case of the ditetragonal pyramid *t*(313), the intercepts are $1a_1$ and $\frac{1}{3}a_2$. This gives the expression $1.\frac{1}{3}.1$ which when cleared of the fraction yields 313,

217



the indices of the face in question. The indices of a prism face like $l(310)$ can be readily obtained in exactly the same manner as described under the Isometric System, Art. 84. p. 75.

III. HEXAGONAL SYSTEM

119. The HEXAGONAL SYSTEM includes all the forms which are referred to four axes, three equal horizontal axes in a common plane intersecting at angles of 60°, and a fourth, vertical axis, at right angles to them.

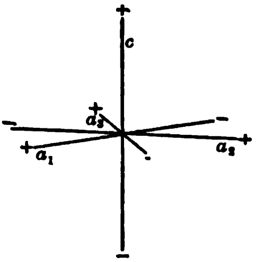
Two sections are here included, each embracing a number of distinct classes related among themselves. They are called the *Hexagonal Division* and the *Trigonal* (or *Rhombohedral*) *Division.* The symmetry of the former, about the vertical axis, belongs to the hexagonal type, that of the latter to the trigonal type.

Miller (1852) referred all the forms of the hexagonal system to three equal axes parallel to the faces of the fundamental rhombohedron, and hence intersecting at equal angles, not 90°. This method (further explained in Art. 169) had the disadvantage of failing to bring out the relationship between the normal hexagonal and tetragonal types, both characterized by a principal axis of symmetry, which (on the system adopted in this book) is the vertical crystallographic axis. It further gave different symbols to faces which are crystallographically identical. It is more natural to employ the three rhombohedral axes for trigonal forms only, as done by Groth (1905), who includes these groups in a *Trigonal System*; but this also has some disadvantages. The indices commonly used in describing hexagonal forms are known as the Miller-Bravais indices, since they were adopted by Bravais for use with the four axes from the scheme used by Miller in the other crystal systems.

120. Symmetry Classes. — There are five possible classes in the Hexagonal Division. Of these the normal class is much the most important, and two others are also of importance among crystallized minerals.

In the Trigonal Division there are seven classes; of these the rhombohedral class or that of the Calcite Type, is by far the most common, and three others are also of importance.

218



Hexagonal Axes

121. Axes and Symbols. — The position of the four axes taken is shown in Fig. 218; the three horizontal axes are called a, since they are equal and interchangeable, and the vertical axis is c, since it has a different length, being either longer or shorter than the horizontal axes. The length of the vertical axis is expressed in terms of that of the horizontal axes which in turn is always taken as unity. Further, when it is desirable to distinguish between the horizontal axes they may be designated a_1, a_2, a_3. When properly orientated one of the horizontal axes (a_2) is parallel to the observer and the other two make angles of 30° either side of the line perpendicular to him. The axis to the left is taken as a_1, the one to the right as a_3. The positive and negative ends of the axes are shown in Fig. 218. The general position of any plane may be expressed in a manner analogous to that applicable in the other systems, viz.

$$\frac{1}{h}a_1 : \frac{1}{k}a_2 : \frac{1}{i}a_3 : \frac{1}{l}c.$$

The corresponding indices for a given plane are then h, k, i, l; these always refer to the axes named in the above scheme. Since it is found convenient to consider the axis a_3 as negative in front and positive behind, the general symbol becomes $hk\bar{i}l$. Further, as following from the angular relation of the three horizontal axes, it can be readily shown to be always true that the algebraic sum of the indices h, k, i, is equal to zero:

$$h + k + i = 0.$$

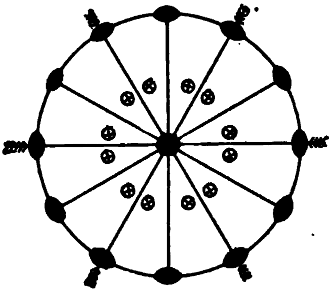
A. Hexagonal Division

1. NORMAL CLASS (13). BERYL TYPE

(Dihexagonal Bipyramidal or Holohedral Class)

122. Symmetry. — Crystals belonging to the normal class of the Hexagonal Division have one principal axis of hexagonal, or sixfold, symmetry, which coincides with the vertical crystallographic axis; also six horizontal axes of binary symmetry; three of these coincide with the horizontal crystallographic axes, the others bisect the angles between them. There is one principal plane of symmetry which is the plane of the horizontal crystallographic axes and six vertical planes of symmetry which meet in the vertical crystallographic axis. Three of these vertical planes include the horizontal crystallographic axes and the other three bisect the angles between the first set.

219



Symmetry of Normal Class

The symmetry of this class is exhibited in the accompanying stereographic projection, Fig. 219, and by the following crystal figures.

The analogy between this class and the normal class of the tetragonal system is obvious at once and will be better appreciated as greater familiarity is gained with the individual forms and their combinations.

123. Forms. — The possible forms in this class are as follows:

	Miller-Bravais.
1. Base	(0001)
2. Prism of the first order	(1010)
3. Prism of the second order	(1120)
4. Dihexagonal prism	($hk\bar{i}0$) as, ($21\bar{3}0$)
5. Pyramid of the first order	($h0\bar{h}l$) as, ($10\bar{1}1$); ($20\bar{2}1$) etc.
6. Pyramid of the second order	($h{\cdot}h{\cdot}2\bar{h}{\cdot}l$) as, ($11\bar{2}2$)
7. Dihexagonal pyramid	($hkil$) as, ($21\bar{3}1$)

In the above $h > k$, and $h + k = -i$.

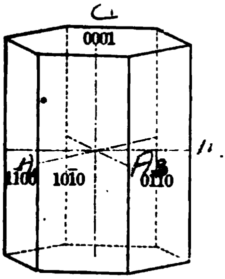
124. Base. — The *base*, or *basal pinacoid*, includes the two faces, 0001 and $000\bar{1}$, parallel to the plane of the horizontal axes. It is uniformly designated by the letter c; see Fig. 220 *et seq.*

125. Prism of the First Order. — There are three types of prisms, or forms in which the faces are parallel to the vertical axis.

The *prism of the first order*, Fig. 220, includes six faces, each one of which is parallel to the vertical axis and meets two adjacent horizontal axes at equal distances, while it is parallel to the third horizontal axis. It has hence the general symbol $(10\bar{1}0)$ and is uniformly designated by the letter *m*; the indices of its six faces taken in order (see Figs. 220 and 229, 230) are:

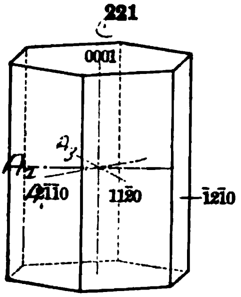
$$10\bar{1}0,\quad 01\bar{1}0,\quad \bar{1}100,\quad \bar{1}010,\quad 0\bar{1}10,\quad 1\bar{1}00.$$

220



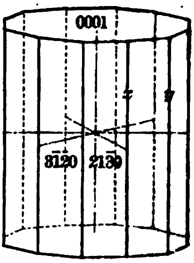
First Order Prism

221



Second Order Prism

222



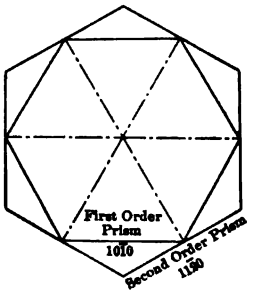
Dihexagonal Prism

126. Prism of the Second Order. — The *prism of the second order*, Fig. 221, has six faces, each one of which is parallel to the vertical axis, and meets the three horizontal axes, two alternate axes at the unit distance, the intermediate axis at one-half this distance; or, which is the same thing, it meets the last-named axis at the unit distance, the others at double this distance.* The general symbol is $(11\bar{2}0)$ and it is uniformly designated by the letter *a*; the indices of the six faces (see Figs. 221 and 229, 230) in order are:

$$11\bar{2}0,\quad \bar{1}2\bar{1}0,\quad \bar{2}110,\quad \bar{1}\bar{1}20,\quad 1\bar{2}10,\quad 2\bar{1}\bar{1}0.$$

The first and second order prisms are not to be distinguished geometrically from each other since each is a regular hexagonal prism with normal interfacial angles of 60°. They are related to each other in the same way as the two prisms $m(110)$ and $a(100)$ of the tetragonal system.

223



The relation in position between the first order prism (and pyramids) on the one hand and the second order prism (and pyramids) on the other will be understood better from Fig. 223, representing a cross section of the two prisms parallel to the base *c*.

127. Dihexagonal Prism. — The *dihexagonal prism*, Fig. 222, is a twelve-sided prism bounded by twelve faces, each one of which is parallel to the vertical axis, and also meets two adjacent horizontal axes at unequal distances, the ratio of which always lies between 1 : 1 and 1 : 2. This prism has two unlike edges, lettered *x* and *y*, as shown in Fig. 222. The general symbol is $(hk\bar{i}0)$ and the indices of the faces of a given form, as $(21\bar{3}0)$, are:

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[*] Since $1a_1 : 1a_2 : -\frac{1}{2}a_3 : \infty c$ is equivalent to $2a_1 : 2a_2 : -1a_3 : \infty c$.

$$\begin{array}{cccccc} 21\bar{3}0, & 1230, & \bar{1}3\bar{2}0, & 23\bar{1}0, & \bar{3}210, & \bar{3}120, \\ \bar{2}\bar{1}30, & \bar{1}\bar{2}30, & 1\bar{3}20, & 2\bar{3}10, & 3\bar{2}\bar{1}0, & 3\bar{1}\bar{2}0. \end{array}$$

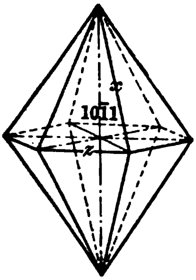
128. Pyramids of the First Order. — Corresponding to the three types of prisms just mentioned, there are three types of pyramids

A *pyramid of the first order*, Fig. 224, is a double six-sided pyramid (or bipyramid) bounded by twelve similar triangular faces — six above and six below — which have the same position relative to the horizontal axes as the faces of the first order prism, while they also intersect the vertical axis above and below. The general symbol is hence $(h0\bar{h}l)$. The faces of a given form, as $10\bar{1}1$), are:

$$\begin{array}{lcccccc} \text{Above} & 10\bar{1}1, & 01\bar{1}1, & \bar{1}101, & \bar{1}011, & 0\bar{1}11, & 1\bar{1}01. \\ \text{Below} & 10\bar{1}\bar{1}, & 01\bar{1}\bar{1}, & \bar{1}10\bar{1}„ & \bar{1}01\bar{1}, & 0\bar{1}1\bar{1}, & 1\bar{1}0\bar{1}. \end{array}$$

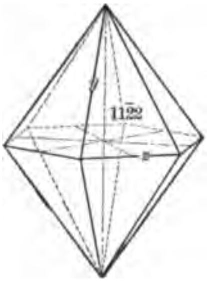
On a given species there may be a number of pyramids of the first order, differing in the ratio of the intercepts on the horizontal to the vertical axis, and thus forming a zone between the base (0001) and the faces of the unit prism $(10\bar{1}0)$. Their symbols, passing from the base (0001) to the unit prism $(10\bar{1}0)$, would be, for example, $10\bar{1}4$, $10\bar{1}2$, $20\bar{2}3$, $10\bar{1}1$, $30\bar{3}2$, $20\bar{2}1$, etc. In Fig. 228 the faces p and u are first order pyramids and they have the symbols respectively $(10\bar{1}1)$ and $(20\bar{2}1)$, here $c = 0.4989$. As shown in these cases the faces of the first order pyramids replace the edges of the first order prism. On the other hand, they replace the solid angles of the second order prism $a(11\bar{2}0)$.

224



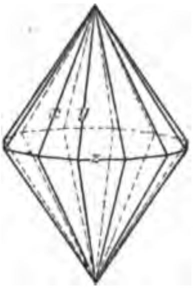
First Order Pyramid

225



Second Order Pyramid

226



Dihexagonal Pyramid

129. Pyramids of the Second Order. — The *pyramid of the second order* (Fig. 225), is a double six-sided pyramid including the twelve similar faces which have the same position relative to the horizontal axes as the faces of the second order prism, and which also intersect the vertical axis. They have the general symbol $(h \cdot h \cdot 2\bar{h} \cdot l)$. The indices of the faces of the form $(11\bar{2}2)$ are:

$$\begin{array}{lcccccc} \text{Above} & 11\bar{2}2, & \bar{1}2\bar{1}2, & \bar{2}112, & \bar{1}\bar{1}22, & 1\bar{2}12, & 2\bar{1}\bar{1}2. \\ \text{Below} & 11\bar{2}\bar{2}, & \bar{1}2\bar{1}\bar{2}, & \bar{2}11\bar{2}, & \bar{1}\bar{1}2\bar{2}, & 1\bar{2}1\bar{2}, & 2\bar{1}\bar{1}\bar{2}. \end{array}$$

The faces of the second order pyramid replace the edges between the faces of the second order prism and the base. Further, they replace the solid angles of the first order prism $m(10\bar{1}0)$. There may be on a single crystal a number of second order pyramids forming a zone between the base $c(0001)$ and the faces of the second order prism $a(11\bar{2}0)$, as, naming them in order: $11\bar{2}4$, $11\bar{2}2$, $22\bar{4}3$, $11\bar{2}1$, etc. In Fig. 227, s is the second order pyramid $(11\bar{2}1)$.

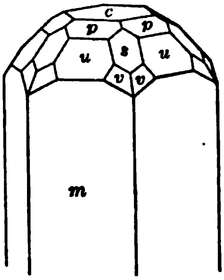
130. Dihexagonal Pyramid. — The *dihexagonal pyramid*, Fig. 226, is a double twelve-sided pyramid, having the twenty-four similar faces embraced under the general symbol $(hk\bar{i}l)$. It is bounded by twenty-four similar faces, each meeting the vertical axis, and also meeting two adjacent horizontal axes at unequal distances, the ratio of which always lies between 1 : 1 and 1 : 2. Thus the form $(21\bar{3}1)$ includes the following twelve faces in the upper half of the crystal:

$$21\bar{3}1,\quad 12\bar{3}1,\quad \bar{1}3\bar{2}1,\quad \bar{2}3\bar{1}1,\quad \bar{3}211,\quad \bar{3}121,$$
$$\bar{2}\bar{1}31,\quad \bar{1}\bar{2}31,\quad 1\bar{3}21,\quad 2\bar{3}11,\quad 3\bar{2}\bar{1}1,\quad 3\bar{1}\bar{2}1.$$

And similarly below with l (here 1) negative, $21\bar{3}\bar{1}$, etc. The dihexagonal pyramid is often called a *berylloid* because a common form with the species beryl. The dihexagonal pyramid $v(21\bar{3}1)$ is shown on Figs. 224, 225.

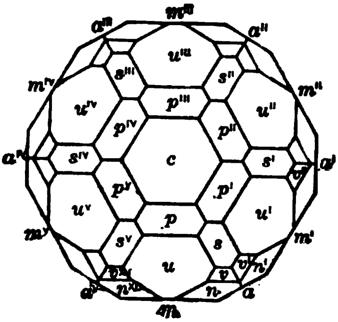
131. Combinations. — Fig. 227 of beryl shows a combination of the base $c(0001)$ and prism $m(1010)$ with the first order pyramids $p(10\bar{1}1)$ and $u(20\bar{2}1)$; the second order pyramid $s(11\bar{2}1)$ and the dihexagonal pyramid $v(21\bar{3}1)$. Both the last forms lie in a zone between m and s, for which it is true that $k = l$. The basal projection of a similar crystal shown in Fig. 228 is very instructive as exhibiting the symmetry of the normal hexagonal class. This is also true of the stereographic and gnomonic projections in Figs. 229 and 230 of a like crystal with the added form $o(11\bar{2}2)$.

227



Beryl

228



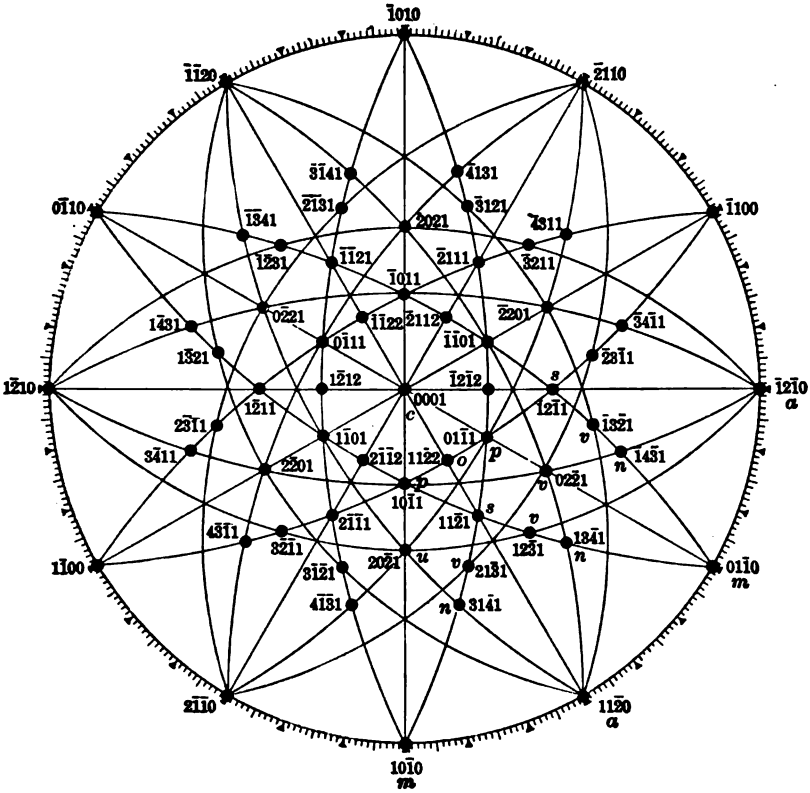
Beryl

2. HEMIMORPHIC CLASS (14). ZINCITE TYPE

(*Dihexagonal Pyramidal or Holohedral Hemimorphic Class*)

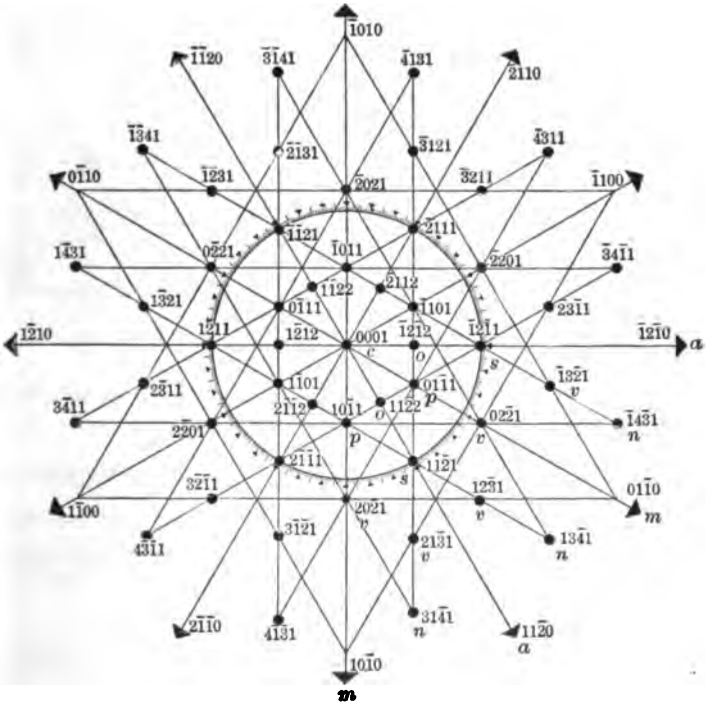
132. Symmetry. — This class differs from the normal class only in having no horizontal plane of principal symmetry and no horizontal axes of binary symmetry. It has, however, the same six vertical planes of symmetry meeting at angles of 30° in the vertical crystallographic axis which is

229



Beryl

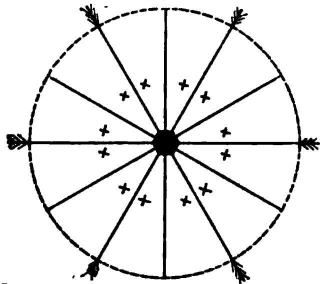
230



Beryl

an axis of hexagonal symmetry. There is no center of symmetry. The symmetry is exhibited in the stereographic projection, Fig. 231.

231



Symmetry of Hemimorphic Class

133. Forms. — The forms belonging to this class are the two basal planes, 0001 and 000$\bar{1}$, here distinct forms, the positive (upper) and negative (lower) pyramids of each of the three types; also the three prisms, which last do not differ geometrically from the prisms of the normal class. An example of this class is found in zincite, Fig. 44, p. 22. Iodyrite, greenockite and wurtzite are also classed here.

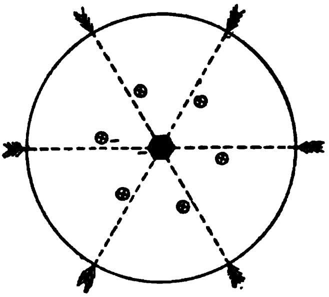
3. TRIPYRAMIDAL CLASS (15). APATITE TYPE

(*Hexagonal Bipyramidal or Pyramidal Hemihedral Class*)

134. Typical Forms and Symmetry. — This class is important because it includes the common species of the Apatite Group, apatite, pyromorphite, mimetite, vanadinite. The typical form is the hexagonal prism $(hk\bar{i}0)$ and the hexagonal pyramid $(hk\bar{i}l)$, each designated as of the *third order*. These forms which are shown in Figs. 233 and 234 may be considered as derived from the corresponding dihexagonal forms of the normal class by the omission of one half of the faces of the latter. They and the other forms of the class have only one plane of symmetry, the plane of the horizontal axes, and also one axis of hexagonal symmetry (the vertical axis).

The symmetry is exhibited in the stereographic projection (Fig. 232). It is seen here, as in the figures of crystals given, that, like the tripyramidal class under the tetragonal system, the faces of the general form $(hk^{-}l)$ present are half of the possible planes belonging to each sectant, and further that those above and below fall in the same vertical zone.

232



Symmetry of Tripyramidal Class

135. Prism and Pyramid of the Third Order. — The prism of the third order (Fig. 233) has six like faces embraced under the general symbol $(hk\bar{i}0)$, and the form is a regular hexagonal prism with angles of 60°, not to be distinguished geometrically, if alone, from the other hexagonal prisms; cf. Figs. 220, 221, p. 96. The six faces of the right-handed form $(21\bar{3}0)$ have the indices

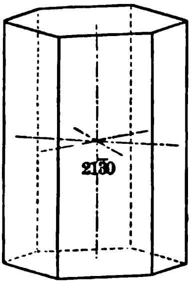
$$21\bar{3}0,\quad \bar{1}3\bar{2}0,\quad \bar{3}210,\quad \bar{2}\bar{1}30,\quad 1\bar{3}20,\quad 3\bar{2}\bar{1}0.$$

The faces of the complementary left-handed form have the indices:

$$12\bar{3}0,\quad \bar{2}3\bar{1}0,\quad \bar{3}120,\quad \bar{1}\bar{2}30,\quad 2\bar{3}10,\quad 3\bar{1}\bar{2}0.$$

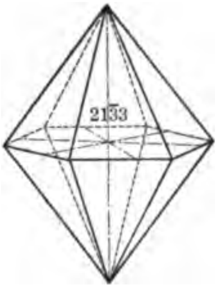
As already stated these two forms together embrace all the faces of the dihexagonal prism (Fig. 222).

233



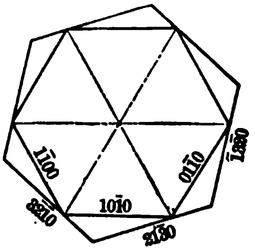
Third Order Prism

234



Third Order Pyramid

235



The pyramid is also a regular double hexagonal pyramid of the third order, and in its relations to the other hexagonal pyramids of the class (Figs. 224, 225) it is analogous to the square pyramid of the third order met with in the corresponding class of the tetragonal system (see Art. **100**). The faces of the right-handed form ($21\bar{3}1$) are:

Above $21\bar{3}1$, $\bar{1}3\bar{2}1$, $\bar{3}21\bar{1}$, $\bar{2}\bar{1}31$, $1\bar{3}21$, $3\bar{2}\bar{1}1$.
Below $21\bar{3}\bar{1}$, $\bar{1}3\bar{2}\bar{1}$, $\bar{3}21\bar{1}$, $\bar{2}\bar{1}3\bar{1}$, $1\bar{3}2\bar{1}$, $3\bar{2}\bar{1}\bar{1}$.

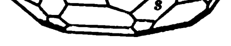
There is also a complementary left-handed form, which with this embraces all the faces of the dihexagonal pyramid. The cross section of Fig. 235 shows in outline the position of the first order prism, and also that of the right-handed prism of the third order.

The prism and pyramid just described do not often appear on crystals as predominating forms, though this is sometimes the case, but commonly these faces are present modifying other fundamental forms.

136. Other Forms. — The remaining forms of the class are geometrically like those of the normal class, viz., the base (0001); the first order prism ($10\bar{1}0$); the second order prism ($11\bar{2}0$); the first order pyramids ($h0\bar{h}l$); and the second order pyramids ($h{\cdot}h{\cdot}\overline{2h}{\cdot}l$). That their molecular structure, however, corresponds to the symmetry of this class is readily proved, for example, by etching. In this way it was shown that pyromorphite and mimetite belonged in the same group with apatite (Baumhauer), though crystals with the typical forms had not been observed. This class is given its name of *Tripyramidal* because its forms include three distinct types of pyramids.

137. A typical crystal of apatite is given in Fig. 236. It shows the third order prism $h(21\bar{3}0)$, and the third order pyramids, $\mu(21\bar{3}1)$, $n(31\bar{4}1)$; also the first order pyramids $r(10\bar{1}2)$, $x(10\bar{1}1)$, $y(20\bar{2}1)$, the second order pyramids $v(11\bar{2}2)$, $s(11\bar{2}1)$; finally, the prism $m(10\bar{1}0)$, and the base $c(0001)$.

236



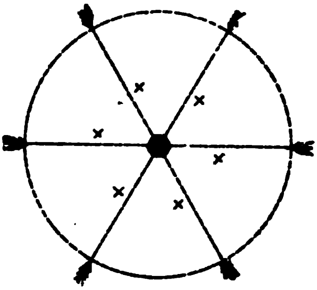
Apatite

4 PYRAMIDAL-HEMIMORPHIC CLASS (16). NEPHELITE TYPE

(*Hexagonal Pyramidal or Pyramidal Hemihedral Hemimorphic Class*)

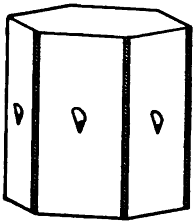
138. Symmetry. — A fourth class under the hexagonal division, the *pyramidal-hemimorphic class*, is like that just described, except that the forms are hemimorphic. The single horizontal plane of symmetry is absent, but the vertical axis is still an axis of hexagonal symmetry. This symmetry is shown in the stereographic projection of Fig. 237. The typical form would be like the upper half of Fig. 234 of the pyramid of the third order. The species nephelite is shown by the character of the etching-figures (Fig. 238, Groth after Baumhauer) to belong here.

237



Symmetry of Pyramidal-Hemimorphic Class

238



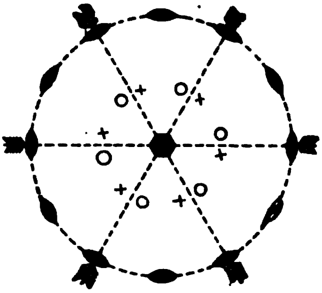
Nephelite

5. TRAPEZOHEDRAL CLASS (17)

(*Hexagonal Trapezohedral or Trapezohedral Hemihedral Class*)

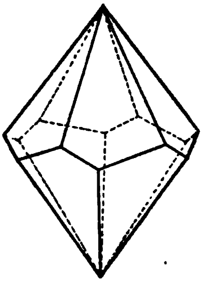
139. Symmetry. — The last class of this division is the *trapezohedral class*. It has no plane of symmetry, but the vertical axis is an axis of hexagonal symmetry, and there are, further, six horizontal axes of binary symmetry. There is no center of symmetry. The symmetry and the distribution of the faces of the typical form (*hkīl*) is shown in the stereographic projection (Fig. 239). The typical forms may be derived from the dihexagonal pyramid by the omission of the alternate faces of the latter. There are two possible types known as the right and left hexagonal trapezohedrons (see Fig. 240), which are enantiomorphous, and the few crystallized salts falling in this class show circular polarization. A modification of quartz known as

239



Symmetry of Trapezohedral Class

240



Hexagonal Trapezohedron

β-quartz is also described as belonging here. The indices of the right form ($21\bar{3}1$) are as follows:

Above $21\bar{3}1$, $\bar{1}3\bar{2}1$, $\bar{3}211$, $\bar{2}\bar{1}31$, $1\bar{3}21$, $3\bar{2}\bar{1}1$.
Below $12\bar{3}\bar{1}$, $\bar{2}3\bar{1}\bar{1}$, $\bar{3}12\bar{1}$, $\bar{1}\bar{2}3\bar{1}$, $2\bar{3}1\bar{1}$, $3\bar{1}\bar{2}\bar{1}$.

B. Trigonal or Rhombohedral Division

(*Trigonal System*)

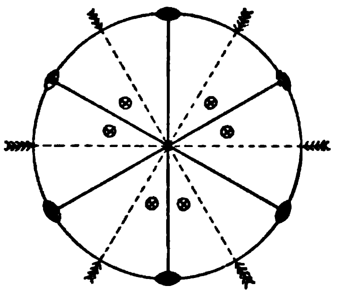
140. *General Character.* — As stated on p. 19, the classes of this division are characterized by a vertical axis of trigonal, or threefold, symmetry. There are seven classes here included of which the rhombohedral class of the Calcite Type is by far the most important.

1. TRIGONAL CLASS (18). BENITOITE TYPE

(*Ditrigonal Bipyramidal, Trigonal Hemihedral or Trigonotype Class*)

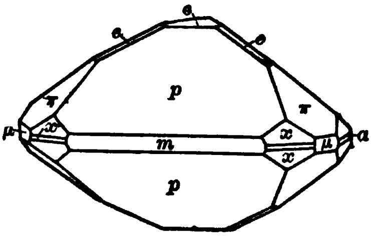
141. Typical Forms and Symmetry. — This class has, besides the vertical axis of trigonal symmetry, three horizontal axes of binary symmetry which are diagonal to the crystallographic axes. There are four planes of symmetry, one horizontal, and three vertical diagonal planes intersecting at angles of 60° in the vertical axis. The symmetry and the distribution of the faces of the positive ditrigonal pyramid is shown in Fig. 241. The characteristic forms are as follows. *Trigonal prism* consisting of three faces comprising one half the faces of the hexagonal prism of the first order. They are of two types, called positive ($10\bar{1}0$) and negative ($01\bar{1}0$). *Trigonal pyramid*, a double three-faced pyramid, consisting of six faces corresponding to one half the faces of the hexagonal pyramid of the first order. The faces of the upper and lower halves fall in vertical zones with each other. There are two types, called positive ($10\bar{1}1$) and negative ($01\bar{1}1$). *Ditrigonal prism* consists of six vertical faces arranged in three similar sets of two faces and having therefore the alternate edges of differing character. It may be derived from the dihexagonal prism by taking alternating pairs of faces. *Ditrigonal pyramid* consists of twelve faces, six above and six below. It, like the prism, may be derived from the dihexagonal form by taking alternate pairs of faces of the latter. The faces of the upper and lower halves fall in vertical

241



Symmetry of Trigonal Class

242



Benitoite (Palache)

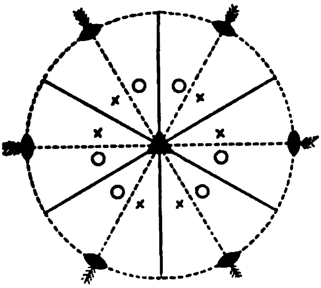
zones. The only representative of this class known is the rare mineral benitoite, a crystal of which is represented in Fig. 242. This crystal shows the trigonal prisms $m(10\bar{1}0)$ and $\mu(01\bar{1}0)$, the hexagonal prism of the second order, $a(11\bar{2}0)$, the trigonal pyramids, $p(10\bar{1}1)$ and $\pi(01\bar{1}1)$; $e(01\bar{1}2)$ and the hexagonal pyramid of the second order, $x(22\bar{4}1)$

2. RHOMBOHEDRAL CLASS (19). CALCITE TYPE

(Ditrigonal Scalenohedral or Rhombohedral Hemihedral Class)

142. Typical Forms and Symmetry. — The typical forms of the *rhombohedral class* are the rhombohedron (Fig. 244) and the scalenohedron (Fig. 259). These forms, with the projections, Figs. 243 and 269, illustrate the symmetry characteristic of the class. There are three planes of symmetry only; these are diangoal to the horizontal crystallographic axes and intersect at angles of 60° in the vertical crystallographic axis. This axis is with these forms an axis of trigonal symmetry; there are, further, three horizontal axes diagonal to the crystallographic axes of binary symmetry. Compare Fig. 244, also Fig. 245 *et seq.*

243

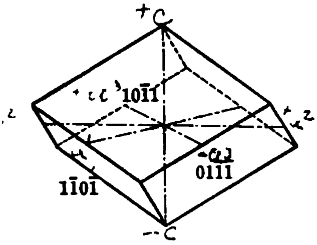


Symmetry of Rhombohedral Class

By comparing Fig. 269 with Fig. 229, p. 99, it will be seen that all the faces in half the sectants are present. This group is hence analogous to the tetrahedral class of the isometric system, and the sphenoidal class of the tetragonal system.

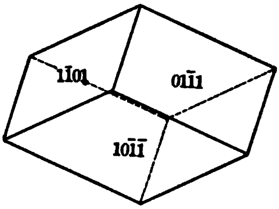
143. Rhombohedron. — Geometrically described, the *rhombohedron* is a solid bounded by six like faces, each a rhomb. It has six like lateral edges forming a zigzag line about the crystal, and six like terminal edges, three above and three in alternate position below. The vertical axis joins the two trihedral solid angles, and the horizontal axes join the middle points of the opposite sides, as shown in Fig. 244.

244



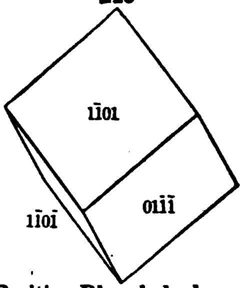
Positive Rhombohedron Calcite

245



Negative Rhombohedron

246



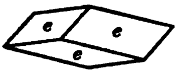
Positive Rhombohedron Hematite

The general symbol of the rhombohedron is $(h0\bar{h}l)$, and the successive faces of the unit form $(10\bar{1}1)$ have the indices:

Above, $10\bar{1}1$, $\bar{1}101$, $0\bar{1}11$; below, $01\bar{1}\bar{1}$, $\bar{1}01\bar{1}$, $1\bar{1}0\bar{1}$.

The geometrical shape of the rhombohedron varies widely as the angles change, and consequently the relative length of the vertical axis *c* (expressed in terms of the horizontal axes, $a = 1$). As the vertical axis diminishes, the rhombohedrons become more and more obtuse or flattened; and as it increases they become more and more acute. A cube placed with an octahedral axis vertical is obviously the limiting case between the obtuse and acute forms where the interfacial angle is 90°. In Fig. 244 of calcite the normal rhombohedral angle is 74° 55′ and $c = 0{\cdot}854$, while for Fig. 246 of hematite this angle is 94° and $c = 1{\cdot}366$. Further, Figs. 246–251 show other rhombohedrons of calcite, namely, $l(01\bar{1}2)$, $\phi(05\bar{5}4)$, $f(02\bar{2}1)$, $M(40\bar{4}1)$, and $\rho(16{\cdot}0{\cdot}\overline{16}{\cdot}1)$; here the vertical axes are in the ratio of $\frac{1}{2}$, $\frac{5}{4}$, 2, 4, 16, to that of the fundamental (cleavage) rhombohedron of Fig. 244, whose angle determines the value of *c*.

247



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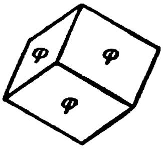

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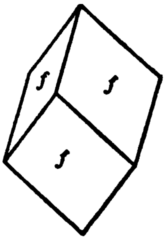

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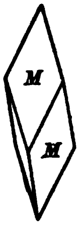

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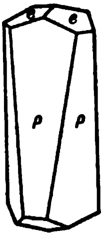

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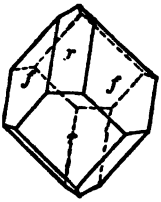

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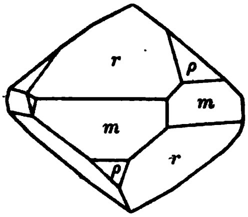
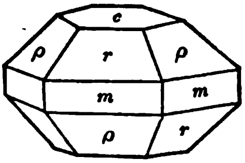


254



Figs. 247-252, Calcite Figs. 253-254, Gmelinite

144. Positive and Negative Rhombohedrons. — To every positive rhombohedron there may be an inverse and complementary form, identical geometrically, but bounded by faces falling in the alternate sectants. Thus the negative form of the unit rhombohedron $(01\bar{1}1)$ shown in Fig. 245 has the faces:

Above, $01\bar{1}1$, $\bar{1}011$, $1\bar{1}01$; below, $\bar{1}10\bar{1}$, $0\bar{1}1\bar{1}$, $10\bar{1}\bar{1}$.

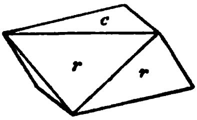
The position of these in the projections (Figs. 269, 270) should be carefully studied. Of the figures already referred to, Figs. 244, 246, 250 are positive, and Figs. 245, 247, 248, 249 negative, rhombohedrons; Fig. 251 shows both forms.

It will be seen that the two complementary positive and negative rhombohedrons of given axial length together embrace all the like faces of the double six-sided hexagonal pyramid of the first order. When these two rhombohedrons are equally developed the form is geometrically identical with this pyramid. This is illustrated by Fig. 254 of gmelinite $r(10\bar{1}1)$,

$\rho(01\bar{1}1)$ and by Figs. 284, 285, p. 113, of quartz, $r(10\bar{1}1)$, $z(01\bar{1}1)$.* In each case the form, which is geometrically a double hexagonal pyramid (in Fig. 254 with *c* and *m*), is in fact a combination of the two unit rhombohedrons, positive and negative. Commonly a difference in size between the two forms may be observed, as in Figs. 253 and 286, where the form taken as the positive rhombohedron predominates. But even if this distinction cannot be established, the two rhombohedrons can always be distinguished by etching, or, as in the case of quartz, by pyro-electrical phenomena.

145. Of the two series, or zones, of rhombohedrons the faces of the *positive rhombohedrons* replace the edges between the base (0001) and the first order prism $(10\bar{1}0)$. Also the faces of the *negative rhombohedrons* replace the alternate edges of the same forms, that is, the edges between (0001) and $(01\bar{1}0)$ (compare Figs. 253, 254, etc.). Fig. 255 shows the rhombohedron in combination with the base. Fig. 256 the same with the prism $a(11\bar{2}0)$. When the angle between the two forms happens to approximate to 70° 32′ the crystal simulates the aspect of a regular octahedron. This is illustrated by Fig. 257; here *co* = 69° 42′, also *oo* = 71° 22′, and the crystal resembles closely an octahedron with truncated edges (cf. Fig. 99, p. 55).

255



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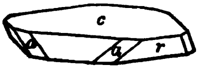

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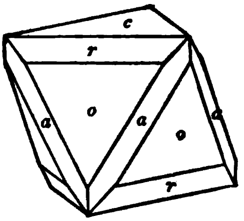

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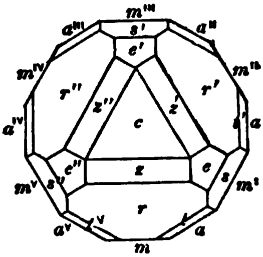

Figs. 255, 256, Hematite Coquimbite Eudialyte

146. There is a very simple relation between the positive and negative rhombohedrons which it is important to remember. The form of one series which truncates the terminal edges of a given form of the other will have one half the intercept on the vertical crystallographic axis of the latter. This ratio is expressed in the values of the indices of the two forms. Thus $(01\bar{1}2)$, truncates the terminal edges of the positive unit rhombohedron $(10\bar{1}1)$; $(10\bar{1}4)$ truncates the terminal edges of $(01\bar{1}2)$, $(10\bar{1}5)$ of $(20\bar{2}5)$. Again $(10\bar{1}1)$ truncates the edges of $(02\bar{2}1)$, $(40\bar{4}1)$ of $(02\bar{2}1)$, etc. This is illustrated by Fig. 252 with the forms $r(10\bar{1}1)$ and $f(02\bar{2}1)$. Also in Fig. 258, a basal projection, $z(10\bar{1}4)$ truncates the edges of $e(01\bar{1}2)$; $e(01\bar{1}2)$ of $r(10\bar{1}1)$; $r(10\bar{1}1)$ of $s(02\bar{2}1)$.

147. Scalenohedron. — The *scalenohedron*, shown in Fig. 259, is the general form for this class corresponding to the symbol $hk\bar{i}l$. It is a solid, bounded by twelve faces, each a scalene triangle. It has roughly the shape of a double six-sided pyramid, but there are two sets of terminal edges, one more obtuse than the other, and the lateral edges form a zigzag edge around the form like that of the rhombohedron. It may be considered as derived from the dihexagonal pyramid by taking the alternating pairs of faces of that form. It is to be noted that the faces in the lower half of the form do not fall in vertical zones with those of the upper half. Like the rhombohedrons, the scalenohedrons may be either positive or negative. The positive forms correspond in position to the positive rhombohedrons and conversely.

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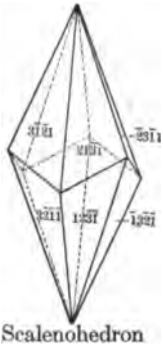
* Quartz serves as a convenient illustration in this case, none the less so notwithstanding the fact that it belongs to the trapezohedral class of this division.

259



Scalenohedron

The positive scalenohedron ($21\bar{3}1$), Fig. 259, has the following indices for the several faces:

Above $21\bar{3}1$, $\bar{2}3\bar{1}1$, $\bar{3}211$, $\bar{1}\bar{2}31$, $1\bar{3}21$, $3\bar{1}\bar{2}1$
Below $12\bar{3}\bar{1}$, $\bar{1}3\bar{2}\bar{1}$, $\bar{3}12\bar{1}$, $\bar{2}\bar{1}3\bar{1}$, $2\bar{3}1\bar{1}$, $3\bar{2}\bar{1}\bar{1}$.

For the complementary negative scalenohedron ($12\bar{3}1$) the indices of the faces are:

Above $12\bar{3}1$, $\bar{1}3\bar{2}1$, $\bar{3}121$, $\bar{2}\bar{1}31$, $2\bar{3}11$, $3\bar{2}\bar{1}1$.
Below $\bar{2}3\bar{1}\bar{1}$, $\bar{3}21\bar{1}$, $\bar{1}\bar{2}3\bar{1}$, $1\bar{3}2\bar{1}$, $3\bar{1}\bar{2}\bar{1}$, $21\bar{3}\bar{1}$.

148. Relation of Scalenohedrons to Rhombohedrons. — It was noted above that the scalenohedron in general has a series of zigzag lateral edges like the rhombohedron. It is obvious, further, that for every rhombohedron there will be a series or zone of scalenohedrons having the *same* lateral edges. This is shown in Fig. 262, where the scalenohedron *v*($21\bar{3}1$) bevels the lateral edges of the fundamental rhombohedron *r*($10\bar{1}1$); the same would be true of the scalenohedron ($32\bar{5}1$), etc. Further, in Fig. 263, the negative scalenohedron *x*($13\bar{4}1$) bevels the lateral edges of the negative rhombohedron *f*($02\bar{2}1$). The relation of the indices which must exist in these cases may be shown to be, for example, for the rhombohedron *r*($10\bar{1}1$), $h = k + l$; again for *f*($02\bar{2}1$), $h + 2l = k$, etc. See also the projections, Figs. 269, 270. Further, the position of the scalenohedron may be defined with reference to its parent rhombohedron. For example, in Fig. 262 the scalenohedron *v*($21\bar{3}1$) has three times the vertical axis of the unit rhombohedron *r*($10\bar{1}1$). Again in Fig. 263 *x*($13\bar{4}1$) has twice the vertical axis of *f*($02\bar{2}1$).

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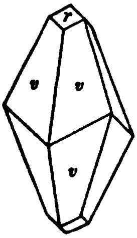

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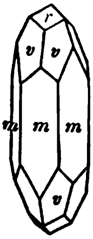

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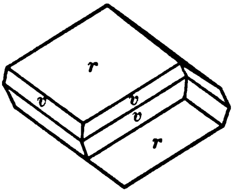

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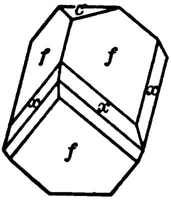
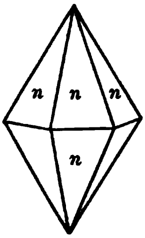


Figs. 260-263, Calcite

264



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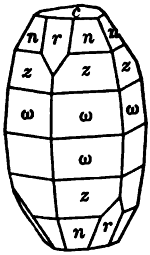
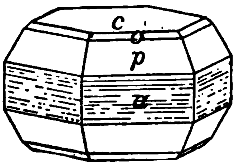


Figs. 264, 265, Corundum

266



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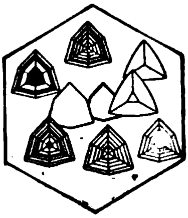

Figs. 266, 267, Spangolite*

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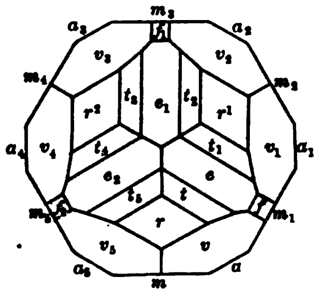
* Spangolite belongs properly to the next (hemimorphic) group, but this fact does not destroy the value of the illustration.

149. Other Forms. — The remaining forms of the normal class of the rhombohedral division are geometrically like those of the corresponding class of the hexagonal division — viz., the base $c(0001)$; the prisms $m(10\bar{1}0)$, $a(11\bar{2}0)$, $(hk\bar{i}0)$; also the second order pyramids, as $(11\bar{2}1)$. Some of these forms are shown in the accompanying figures. For further illustrations reference may be made to typical rhombohedral species, as calcite, hematite, etc.

268



Calcite

With respect to the second order pyramid, it is interesting to note that if it occurs alone (as in Fig. 264, $n = 22\bar{4}3$) it is impossible to say, on geometrical grounds, whether it has the trigonal symmetry of the rhombohedral type or the hexagonal symmetry of the hexagonal type. In the latter case, the form might be made a first order pyramid by exchanging the axial and diagonal planes of symmetry. The true symmetry, however, is often indi-

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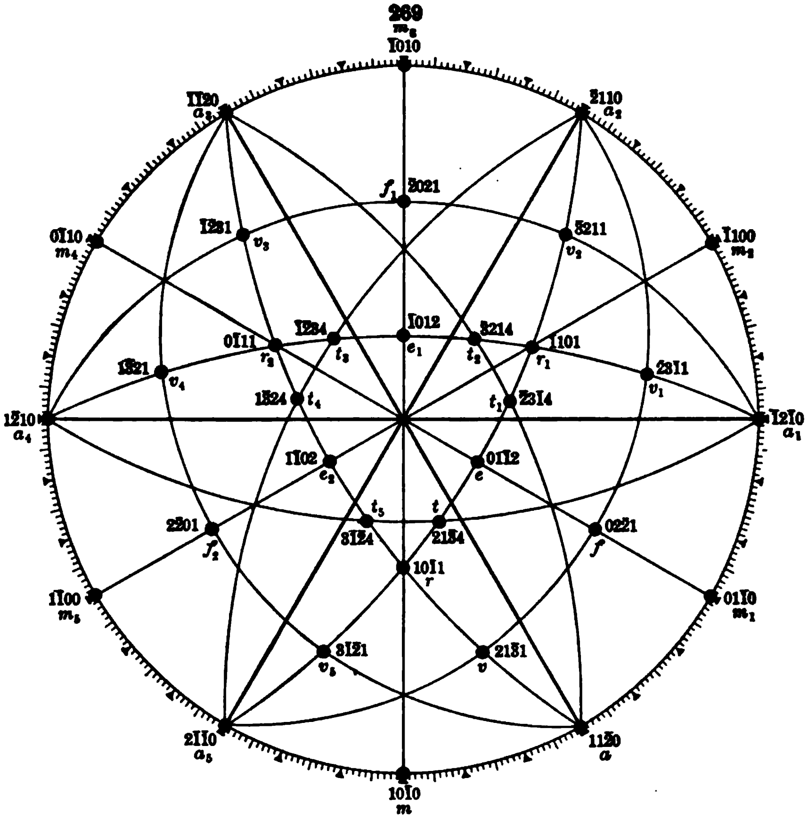
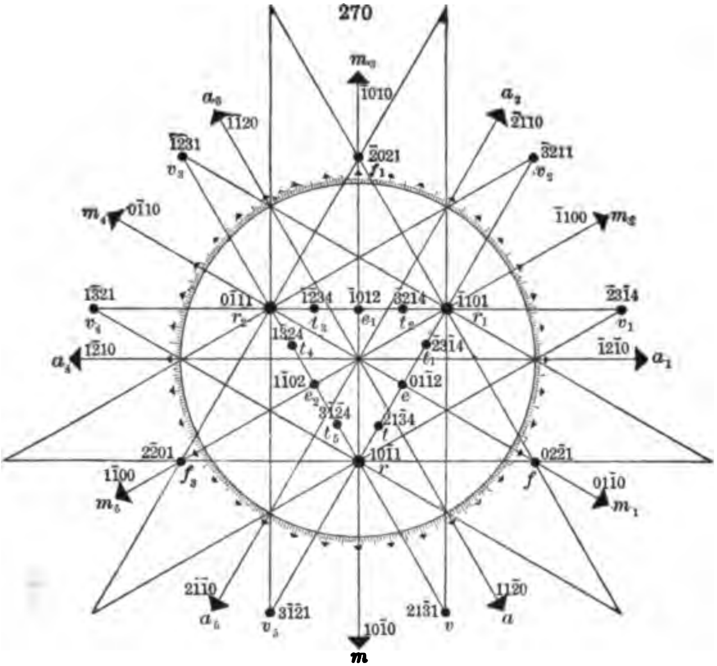


Calcite

cated, as with corundum, by the occurrence on other crystals of rhombohedral faces, as $r(10\bar{1}1)$ in Fig. 265 (here $z = 22\bar{4}1$, $\omega = 14{\cdot}14{\cdot}\overline{28}{\cdot}3$). Even if rhombohedral faces are absent (Fig. 266), the etching-figures (Fig. 267) will often serve to reveal the true trigonal molecular symmetry; here $o = (11\bar{2}4)$, $p = (11\bar{2}2)$.

150. A basal projection of a somewhat complex crystal of calcite is given in Fig. 268, and stereographic and gnomonic projections of the same forms in Figs. 269 and 270; both show well the symmetry in the distribution of the faces. Here the forms are: prisms, $a(11\bar{2}0)$, $m(10\bar{1}0)$; rhombohedrons, positive, $r(10\bar{1}1)$, negative, $e(01\bar{1}2)$, $f(02\bar{2}1)$; scalenohedrons, positive, $v(21\bar{3}1)$, $t(21\bar{3}4)$.

270



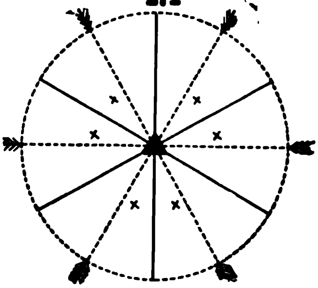
Calcite

3. RHOMBOHEDRAL-HEMIMORPHIC CLASS (20). TOURMALINE TYPE

(Ditrigonal Pyramidal or Trigonal Hemihedral Hemimorphic Class)

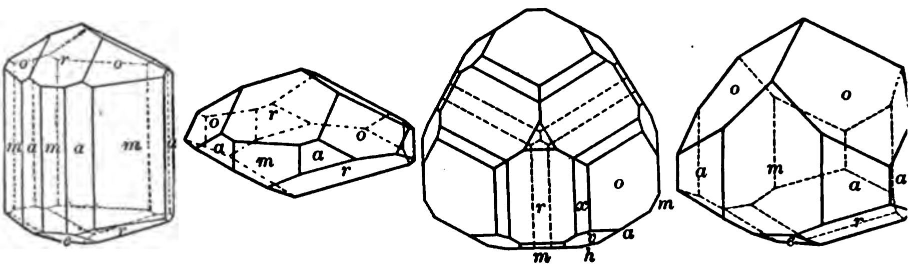
151. Symmetry. — A number of prominent rhombohedral species, as tourmaline, pyrargyrite, proustite, belong to a hemimorphic class under this division. For them the symmetry in the grouping of the faces differs at the two extremities of the vertical axis. The forms have the same three diagonal planes of symmetry meeting at angles of 60° in the vertical axis,

271



Symmetry of Rhombohedral-Hemimorphic Class which is an axis of trigonal symmetry. There are, however, no horizontal axes of symmetry, as in the rhombohedral class, and there is no center of symmetry. Cf. Fig. 271.

152. Typical Forms. — In this class the basal planes (0001) and $(000\bar{1})$ are distinct forms. The other characteristic forms are the two trigonal prisms $m(10\bar{1}0)$ and $m_{,}(01\bar{1}0)$ of the first order series; also the four trigonal first order pyramids, corresponding respectively to the three upper and three lower faces of a positive rhombohedron, and the three upper and three lower faces of the negative rhombohedron; also the hemimorphic second order hexagonal pyramid; finally, the four ditrigonal pyramids, corresponding to the upper and lower faces respectively of the positive and negative scalenohedrons. Figs. 272–275 illustrate these forms. Fig. 274 is a basal section with $r_{,}(01\bar{1}\bar{1})$ and $e_{,}(10\bar{1}\bar{2})$ below.


272 273 274 275

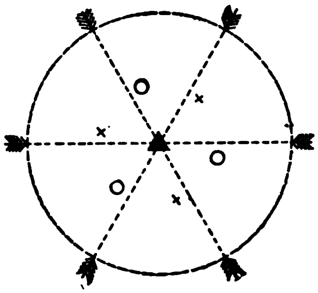
Figs. 272-275, Tourmaline

4. TRI-RHOMBOHEDRAL CLASS (21). PHENACITE TYPE

(Rhombohedral or Rhombohedral Tetartohedral Class)

153. Symmetry. — This class, illustrated by the species dioptase, phenacite, willemite, dolomite, ilmenite, etc., is an important one. It is characterized by the absence of all planes of symmetry, but the vertical axis is still an axis of trigonal symmetry, and there is a center of symmetry. Cf. Fig. 276.

276



Symmetry of Tri-Rhombohedral Class

154. Typical Forms. — The distinctive forms of the class are the rhombohedron of the second order and the hexagonal prism and rhombohedron, each of the third order. The class is thus characterized by three rhombohedrons of distinct types (each + and –), and hence the name given to it.

The *second order rhombohedron* may be derived by taking one half the faces of the normal hexagonal pyramid of the second order. There will be two complementary forms known as positive and negative. For example, in a given case the indices of the faces for the positive and negative forms are:

Positive (above) $11\bar{2}2$, $\bar{2}112$, $1\bar{2}12$; (below) $\bar{1}2\bar{1}\bar{2}$, $\bar{1}\bar{1}2\bar{2}$, $2\bar{1}\bar{1}\bar{2}$,
Negative (above) $\bar{1}2\bar{1}2$, $\bar{1}\bar{1}22$, $2\bar{1}\bar{1}2$; (below) $\bar{2}11\bar{2}$, $1\bar{2}1\bar{2}$, $11\bar{2}\bar{2}$.

The *rhombohedron of the third order* has the general symbol $(hk\bar{i}l)$, and may be derived from the normal dihexagonal pyramid, Fig. 226, by taking one quarter of the faces of the latter.

There are therefore four complementary third order rhombohedrons, distinguished respectively as positive right-handed $(21\bar{3}1)$, positive left-handed $(3\bar{1}\bar{2}1)$, negative right-handed $(\bar{1}3\bar{2}1)$, and negative left-handed $(12\bar{3}1)$. The indices of the six like faces of the positive right-handed form $(21\bar{3}1)$ are:

Above $21\bar{3}1$, $\bar{3}211$, $1\bar{3}21$; below $\bar{1}3\bar{2}\bar{1}$, $\bar{2}\bar{1}3\bar{1}$, $3\bar{2}\bar{1}\bar{1}$.

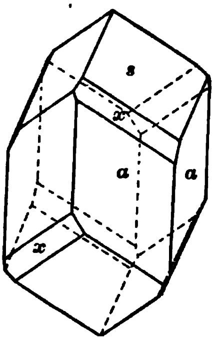
The *hexagonal prism of the third order* may be derived from the normal dihexagonal prism, Fig. 219, by taking one half the faces of the latter. There are two complementary forms known as right- and left-handed. The faces of these forms in a given case $(21\bar{3}0)$ have the indices:

Right	$21\bar{3}0$,	$\bar{1}3\bar{2}0$,	$\bar{3}210$,	$\bar{2}\bar{1}30$,	$1\bar{3}20$,	$3\bar{2}\bar{1}0$,
Left	$12\bar{3}0$	$\bar{2}3\bar{1}0$	$\bar{3}120$	$\bar{1}\bar{2}30$	$2\bar{3}10$,	$3\bar{1}\bar{2}0$.

155. The remaining forms are geometrically like those of the rhombohedral class, viz.: Base $c(0001)$; first order prism $m(10\bar{1}0)$; second order prism $a(11\bar{2}0)$; rhombohedrons of the first order, as $(10\bar{1}1)$ and $(01\bar{1}1)$, etc.

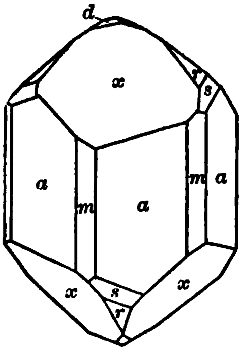
156. The forms of this group are illustrated by Figs. 277–279. Fig. 277 is of dioptase and shows the hexagonal prism of the second order $a(11\bar{2}0)$ with a negative first order rhombohedron, $s(02\bar{2}1)$ and the third order rhombohedron $x(13\bar{4}1)$. Figs. 278 and 279 show the horizontal and clinographic projections of a crystal of phenacite with the following forms: first order prism, $m(10\bar{1}0)$; second order prism, $a(11\bar{2}0)$; third order rhombohedrons, $x(12\bar{3}2)$ and $s(21\bar{3}1)$; first order rhombohedrons, $r(10\bar{1}1)$ and $d(01\bar{1}2)$.

277

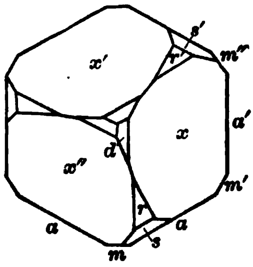


Dioptase

278



279

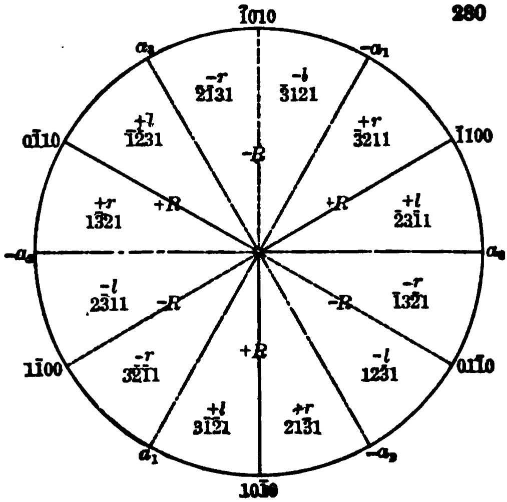


Phernacite

In order to make clearer the relation of the faces of the different types of forms under this class, Fig. 280 is added. Here the zones of the positive and negative rhombohedrons of the first order are indicated ($+R$ and $-R$) also the general positions of the four types of the third order rhombohedrons ($+r$, $-r$, $+l$, $-l$).

The following scheme may also be helpful in connection with Fig. 280. It

280



shows the distribution of the faces of the four rhombohedrons of the third order ($+r$, $+l$, $-r$, $-l$) relatively to the faces of the unit hexagonal prism ($10\bar{1}0$).

PHENACITE TYPE

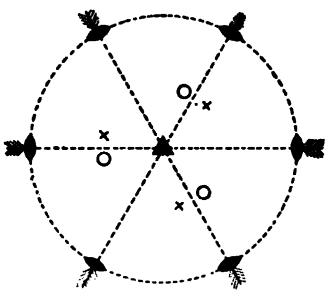
$+l$ $+r$	$-l$ $-r$	$+l$ $+r$	$-l$ $-r$	$+l$ $+r$	$-l$ $-r$
$3\bar{1}\bar{2}1$ $21\bar{3}1$	$12\bar{3}1$ $\bar{1}3\bar{2}1$	$\bar{2}3\bar{1}1$ $\bar{3}211$	$\bar{3}121$ $\bar{2}\bar{1}31$	$\bar{1}\bar{2}31$ $1\bar{3}21$	$2\bar{3}11$ $3\bar{2}\bar{1}1$
$10\bar{1}0$	$01\bar{1}0$	$\bar{1}100$	$\bar{1}010$	$0\bar{1}10$	$1\bar{1}00$
$-l$ $-r$	$+l$ $+r$	$-l$ $-r$	$+l$ $+r$	$-l$ $-r$	$+l$ $+r$
$3\bar{1}\bar{2}\bar{1}$ $21\bar{3}\bar{1}$	$12\bar{3}\bar{1}$ $\bar{1}3\bar{2}\bar{1}$	$\bar{2}3\bar{1}\bar{1}$ $\bar{3}21\bar{1}$	$\bar{3}12\bar{1}$ $\bar{2}\bar{1}3\bar{1}$	$\bar{1}\bar{2}3\bar{1}$ $1\bar{3}2\bar{1}$	$2\bar{3}1\bar{1}$ $3\bar{2}\bar{1}\bar{1}$

5. TRAPEZOHEDRAL CLASS (22). QUARTZ TYPE

(Trigonal Trapezohedral or Trapezohedral Tetartohedral Class)

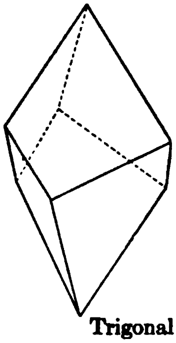
157. Symmetry. — This class includes, among minerals, the species quartz and cinnabar. The forms have no plane of symmetry and no center of symmetry; the vertical axis is, however, an axis of trigonal symmetry, and there are also three horizontal axes of binary symmetry, coinciding in direction with the crystallographic axes; cf. Fig. 281

281

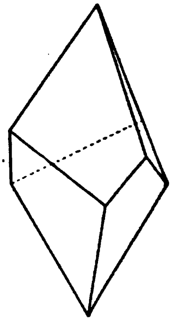


Symmetry of Trapezohedral Class

282



283



Trigonal Trapezohedrons

158. Typical Forms. — The characteristic form of the class is the trigonal trapezohedron shown in Fig. 282. This is the general form corresponding to the symbol $(hk\bar{i}l)$, the faces being distributed as indicated in the accompanying stereographic projection (Fig. 281). The faces of this form correspond to one quarter of the faces of the normal dihexagonal pyramid, Fig. 226. There are therefore four such trapezohedrons, two positive, called respectively right-handed (Fig. 282) and left-handed (Fig. 283), and two similar negative forms, also right- and left-handed (see the scheme given in Art. 160). It is obvious that the two forms of Figs. 282, 283 are enantiomorphous, and circular polarization is a striking character of the species belonging to the class as elsewhere discussed.

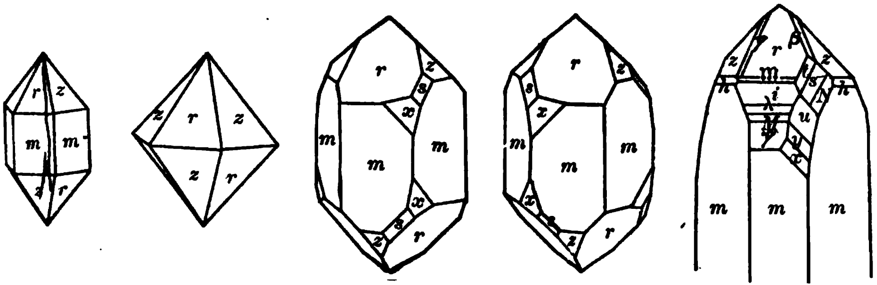
The indices of the six faces belonging to each of these will be evident on consulting Figs. 281 and 229 and 230. The complementary positive form (r and l) of a given symbol include the twelve faces of a positive scalenohedron, while the faces of all four as already stated include the twenty-four faces of the dihexagonal pyramid.

Corresponding to these trapezohedrons there are two *ditrigonal prisms*, respectively right- and left-handed, as $(21\bar{3}0)$ and $(3\bar{1}\bar{2}0)$.

The remaining characteristic forms are the right- and left-handed *trigonal prism* $a(11\bar{2}0)$ and $a(2\bar{1}\bar{1}0)$; also the right- and left-handed *trigonal pyramid*, as $(11\bar{2}2)$ and $(2\bar{1}\bar{1}2)$. They may be derived by taking respectively one half the faces of the hexagonal prism of the second order $(11\bar{2}0)$ or of the corresponding pyramid $(11\bar{2}2)$; these are shown in Figs. 221 and 225.

159. Other Forms. — The other forms of the class are geometrically like those of the normal class. They are the base $c(0001)$, the hexagonal first order prism $m(10\bar{1}0)$, and the positive and negative rhombohedrons as $(10\bar{1}1)$ and $(01\bar{1}1)$. These cannot be distinguished geometrically from the normal forms.

160. Illustrations. — The forms of this class are best shown in the species quartz. As already remarked (p. 106), simple crystals often appear to be of normal hexagonal symmetry, the rhombohedrons $r(10\bar{1}1)$ and $z(01\bar{1}1)$ being equally developed (Figs. 284, 285). In many cases, however, a difference in molecular character between them can be observed, and more commonly one rhombohedron, $r(10\bar{1}1)$, predominates in size; the distinction can always be made out by etching. Some crystals, like Fig. 286, show as modifying faces the *right* trigonal pyramid $s(11\bar{2}1)$, with a *right positive* trapezohedron, as $x(51\bar{6}1)$. Such crystals are called right-handed and rotate



Figs. 284-288, Quartz

the plane of polarization of light transmitted in the direction of the vertical axis to the right. A crystal, like Fig. 287, with the *left* trigonal pyramid $s(2\bar{1}11)$ and one or more *left* trapezohedrons, as $x(6\bar{1}\bar{5}1)$, is called left-handed, and as regards light has the opposite character to the crystal of Fig. 286. Fig. 288 shows a more complex right-handed crystal with several positive and negative rhombohedrons, several positive right trapezohedrons and the negative left trapezohedron, *N*.

The following scheme shows the distribution of the faces of the four trapezohedrons ($+r$, $+l$, $-r$, $-l$) relatively to the faces of the unit hexagonal prism $(10\bar{1}0)$; it is to be compared with the corresponding scheme. given in Art. **156**, of crystals of the phenacite type. In the case of the negative forms some authors prefer to make the faces $21\bar{3}\bar{1}$, $12\bar{3}1$, etc., *right*, and $3\bar{1}\bar{2}\bar{1}$, $\bar{1}3\bar{2}1$, etc., *left*.

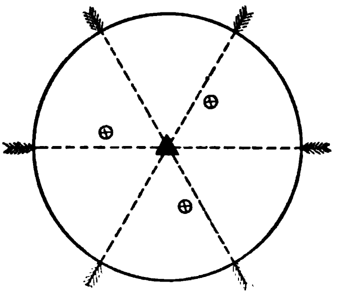
QUARTZ TYPE

$+l$ $+r$	$-l$ $-r$	$+l$ $+r$	$-l$ $-r$	$+l$ $+r$	$-l$ $-r$
$3\bar{1}\bar{2}1$ $21\bar{3}1$	$12\bar{3}1$ $\bar{1}3\bar{2}1$	$\bar{2}3\bar{1}1$ $\bar{3}211$	$\bar{3}121$ $\bar{2}\bar{1}31$	$\bar{1}\bar{2}31$ $1\bar{3}21$	$2\bar{3}11$ $3\bar{2}\bar{1}1$
$10\bar{1}0$	$01\bar{1}0$	$\bar{1}100$	$\bar{1}010$	$0\bar{1}10$	$1\bar{1}00$
$-r$ $-l$	$+r$ $+l$	$-r$ $-l$	$+r$ $+l$	$-r$ $-l$	$+r$ $+l$
$3\bar{1}\bar{2}\bar{1}$ $21\bar{3}\bar{1}$	$12\bar{3}\bar{1}$ $\bar{1}3\bar{2}\bar{1}$	$\bar{2}3\bar{1}\bar{1}$ $\bar{3}21\bar{1}$	$\bar{3}12\bar{1}$ $\bar{2}\bar{1}3\bar{1}$	$\bar{1}\bar{2}3\bar{1}$ $1\bar{3}2\bar{1}$	$2\bar{3}1\bar{1}$ $3\bar{2}\bar{1}\bar{1}$

161. Other Classes. — The next class (23) is known as the Trigonal Bipyramidal or Trigonal Tetartohedral class. It has one plane of symmetry — that of the horizontal axes, and one axis of trigonal symmetry — the vertical axis. There is no center of symmetry. Its characteristic forms are the three types of trigonal prisms and the three corresponding types of trigonal pyramids. Cf. Fig. 289. This class has no known representation among crystals.

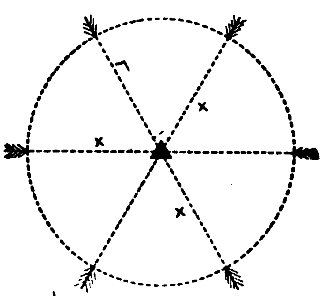
The last class (24) of this division is known as the Trigonal Pyramidal or Trigonal Tetartohedral Hemimorphic class. It has no plane of symmetry and no center of symmetry, but the vertical axis is an axis of trigonal symmetry. The forms are all hemimorphic, the prisms trigonal prisms, and the pyramids hemimorphic trigonal pyramids. Cf. Fig. 290. The crystals of sodium periodate belong to this class.

289



Symmetry of Trigonal Bipyramidal Class

290



Symmetry of the Trigonal Pyramidal Class

MATHEMATICAL RELATIONS OF THE HEXAGONAL SYSTEM.

162. Choice of Axis. — The position of the vertical crystallographic axis is fixed in all the classes of this system since it coincides with the axis of hexagonal symmetry in the hexagonal division and that of trigonal symmetry in the rhombohedral division. The three horizontal axes are also fixed in direction except in the normal class and the subordinate hemimorphic class of the hexagonal division; in these there is a choice of two positions according to which of the two sets of vertical planes of symmetry is taken as the axial set.

163. Axial and Angular Elements. — The axial element is the length of the vertical axis, *c*, in terms of a horizontal axis, *a*; in other words, the axial ratio of *a* : *c*. A single measured angle (in any zone but the prismatic) may be taken as the fundamental angle from which the axial ratio can be obtained.

The angular element is usually taken as the angle between the base *c*(0001) and the unit first order pyramid ($10\bar{1}1$), that is, $0001 \wedge 10\bar{1}1$.

The relation between this angle and the axis *c* is given by the formula

$$\tan\,(0001 \wedge 10\bar{1}1) \times \frac{1}{2}\sqrt{3} = c.$$

The vertical axis is also easily obtained from the unit second order pyramid, since

$$\tan\,(0001 \wedge 11\bar{2}2) = c.$$

These relations become general by writing them as follows:

$$\tan\,(0001 \wedge h0\bar{h}l) \times \frac{1}{2}\sqrt{3} = \frac{h}{l} \times c;$$

$$\tan\,(0001 \wedge h{\cdot}h{\cdot}\overline{2h}{\cdot}l) = \frac{2h}{l} \times c.$$

In general it is easy to obtain any required angle between the poles of two faces on the spherical projection either by the use of the tangent (or cotangent) relation, or by the solution of spherical triangles, or by the application of both methods. In practice most of the triangles used in calculation are right-angled.

164. Tangent and Cotangent Relations. — The tangent relation holds good in any zone from *c*(0001) to a face in the prismatic zone. For example:

$$\frac{\tan\,(0001 \wedge h0\bar{h}l)}{\tan\,(0001 \wedge 10\bar{1}1)} = \frac{h}{l}; \quad \frac{\tan\,(0001 \wedge h{\cdot}h{\cdot}\overline{2h}{\cdot}l)}{\tan\,(0001 \wedge 11\bar{2}2)} = \frac{2h}{l}.$$

In the prismatic zone, the cotangent formula takes a simplified form; for example, for a dihexagonal prism, $hk\bar{i}0$, as ($21\bar{3}0$):

$$\cot\,(10\bar{1}0 \wedge hk\bar{i}0) = \frac{2h+k}{k}\sqrt{\frac{1}{3}};$$

$$\cot\,(11\bar{2}0 \wedge hk\bar{i}0) = \frac{h+k}{h-k}\sqrt{3}.$$

The sum of the angles ($10\bar{1}0 \wedge hk\bar{i}0$) and ($11\bar{2}0 \wedge hk\bar{i}0$) is equal to 30°.

Further, the last equations can be written in a more general form, applying to any pyramid ($hk\bar{i}l$) in a zone, first between $10\bar{1}0$ and a face in the zone 0001 to $01\bar{1}0$, where the angle between $10\bar{1}0$ and this face is known; or again, for the same pyramid, in a zone between $11\bar{2}0$ and a face in the zone 0001 to $10\bar{1}0$, the angle between $11\bar{2}0$ and this face being given. For example (cf. Fig. 229, p. 99), if the first-mentioned zone is $10\bar{1}0{\cdot}hk\bar{i}l{\cdot}01\bar{1}1$ and the second is $11\bar{2}0{\cdot}hk\bar{i}l{\cdot}10\bar{1}1$, then

$$\cot\,(10\bar{1}0 \wedge hk\bar{i}l) = \cot\,(10\bar{1}0 \wedge 01\bar{1}1)\,.\,\frac{2h+k}{k},$$

and

$$\cot\,(11\bar{2}0 \wedge hk\bar{i}l) = \cot\,(11\bar{2}0 \wedge 10\bar{1}1)\,.\,\frac{h+k}{h-k}.$$

Also similarly for other zones,

$$\cot\,(10\bar{1}0 \wedge hk\bar{i}l) = \cot\,(10\bar{1}0 \wedge 02\bar{2}1)\,.\,\frac{2h+k}{k}, \text{ etc.}$$

$$\cot\,(11\bar{2}0 \wedge hk\bar{i}l) = \cot\,(11\bar{2}0 \wedge 20\bar{2}1)\,.\,\frac{h+k}{h-k},\ \text{etc.}$$

165. Other Angular Relations. — The following simple relations are of frequent use:
(1) For a *hexagonal pyramid of the first order,*

$$\tan\tfrac{1}{2}\,(10\bar{1}1 \wedge 01\bar{1}1) = \sin\xi\sqrt{\tfrac{1}{3}},\quad \text{where } \tan\xi = c,$$

and in general

$$\tan\tfrac{1}{2}\,(h0\bar{h}l \wedge 0h\bar{h}l) = \sin\xi_{\prime}\sqrt{\tfrac{1}{3}},\quad \text{where } \tan\xi_{\prime} = \frac{h}{l}c.$$

(2) For a *hexagonal pyramid of the second order,* as $(11\bar{2}2)$,

$$2\sin\tfrac{1}{2}\,(11\bar{2}2 \wedge \bar{1}2\bar{1}2) = \sin\xi,\qquad \text{and}\qquad \tan\xi = c.$$

(3) For a *rhombohedron*

$$\sin\tfrac{1}{2}\,(10\bar{1}1 \wedge \bar{1}101) = \sin\alpha\sqrt{\tfrac{3}{4}},\quad \text{where } \alpha = (0001 \wedge 10\bar{1}1);$$

in general

$$\sin\tfrac{1}{2}\,(h0\bar{h}l \wedge \bar{h}h0l) = \sin\alpha_{\prime}\sqrt{\tfrac{3}{4}},\ \text{where } \alpha_{\prime} = (0001 \wedge h0\bar{h}l).$$

166. Zonal Relations. — The zonal equations, described in Arts 45, 46, apply here as in other systems, only that it is to be noted that one of the indices referring to the horizontal axes, preferably the third, i, is to be dropped in the calculations and only the other three employed. Thus the indices (u, v, w) of the zone in which the faces $(hk\bar{i}l)$, $(pq\bar{r}t)$ lie are given by the scheme

$$\begin{array}{c|cccc|c} h & k & l & h & k & l \\ p & q & t & p & q & t \end{array}$$

where $\qquad u = kt - lq, \qquad v = lp - ht, \qquad w = hq - kp.$

For example (Fig. 226) the face n lies in the zone mv, $10\bar{1}0\cdot21\bar{3}1$ and also in the zone au, $11\bar{2}0\cdot20\bar{2}1$. For the first zone the values obtained are: $u = 0$, $v = \bar{1}$, $w = 1$; for the second zone, $e = 1$, $f = \bar{1}$, $g = \bar{2}$. Combining these zone symbols according to the usual scheme

$$\begin{array}{c|cccc|c} 0 & \bar{1} & 1 & 0 & \bar{1} & 1 \\ 1 & \bar{1} & \bar{2} & 1 & \bar{1} & \bar{2} \\ \hline & 3 & 1 & 1 & & \end{array}$$

The face n has, therefore, the indices $31\bar{4}1$, since further $i = -(h+k)$.

167. Formulas. — The following formulas in which c equals the unit length of the vertical axis are sometimes useful:

(1) The distances (see Fig. 229) of the pole of any face $(hk\bar{i}l)$ from the poles of the faces $(10\bar{1}0)$, $(01\bar{1}0)$, $(\bar{1}100)$, and (0001) are given by the following equations,

$$\cos\,(hk\bar{i}l)\,(10\bar{1}0) = \frac{c\,(k+2h)}{\sqrt{3l^2 + 4c^2\,(h^2+k^2+hk)}}.$$

$$\cos\,(hk\bar{i}l)\,(01\bar{1}0) = \frac{c\,(2k+h)}{\sqrt{3l^2 + 4c^2\,(h^2+k^2+hk)}}.$$

$$\cos\,(hk\bar{i}l)\,(\bar{1}100) = \frac{c\,(h-k)}{\sqrt{3l^2 + 4c^2\,(h^2+k^2+hk)}}.$$

$$\cos\,(hk\bar{i}l)\,(0001) = \frac{l\sqrt{3}}{\sqrt{3l^2 + 4c^2\,(h^2+k^2+hk)}}.$$

(2) The distance (PQ) between the poles of any two faces $P(hk\bar{i}l)$ and $Q(pq\bar{r}t)$ is given by the equation

$$\cos PQ = \frac{3lt + 2c^2(hq + pk + 2hp + 2kq)}{\sqrt{[3l^2 + 4c^2(h^2 + k^2 + hk)]\,[3t^2 + 4c^2(p^2 + q^2 + pq)]}}.$$

(3) For special cases the above formula becomes simplified; it serves to give the valuc of the normal angles for the several forms in the system. They are as follows:

(*a*) *Pyramid of First Order* $(h0hl)$, Fig. 224:

$$\cos X \text{ (terminal)} = \frac{3l^2 + 2h^2c^2}{3l^2 + 4h^2c^2}; \quad \cos Z \text{ (basal)} = \frac{4h^2c^2 - 3l^2}{3l^2 + 4h^2c^2}.$$

(*b*) *Pyramid of Second Order* $(h\cdot h\cdot\overline{2h}\cdot l)$, Fig. 225:

$$\cos Y \text{ (terminal)} = \frac{l^2 + 2c^2h^2}{l^2 + 4c^2h^2}; \quad \cos Z \text{ (basal)} = \frac{4c^2h^2 - l^2}{l^2 + 4c^2h^2}.$$

(*c*) *Dihexagonal Pyramid* $(hk\bar{i}l)$:

$$\cos X \text{ (see Fig. 226)} = \frac{3l^2 + 2c^2(h^2 + k^2 + 4hk)}{3l^2 + 4c^2(h^2 + k^2 + hk)}.$$

$$\cos Y \text{ (see Fig. 226)} = \frac{3l^2 + 2c^2(2h^2 + 2hk - k^2)}{3l^2 + 4c^2(h^2 + k^2 + hk)}.$$

$$\cos Z \text{ (basal)} = \frac{4c^2(h^2 + k^2 + hk) - 3l^2}{3l^2 + 4c^2(h^2 + k^2 + hk)}.$$

(*d*) *Dihexagonal Prism* $(hk\bar{i}0)$, Fig. 222:

$$\cos X \text{ (axial)} = \frac{h^2 + k^2 + 4hk}{2(h^2 + k^2 + hk)}. \qquad \cos Y \text{ (diagonal)} = \frac{2h^2 + 2hk - k^2}{2(h^2 + k^2 + hk)}.$$

(*e*) *Rhombohedron* $(10\bar{1}1)$:

$$\cos X \text{ (terminal)} = \frac{3l^2 - 2h^2c^2}{3l^2 + 4h^2c^2}.$$

(*f*) *Scalenohedron* $(hk\bar{i}l)$:

$$\cos X \text{ (see Fig. 259)} = \frac{3l^2 + 2c(2k^2 + 2hk - h^2)}{3l^2 + 4c^2(h^2 + k^2 + hk)}.$$

$$\cos Y \text{ (see Fig. 259)} = \frac{3l^2 + 2c^2(2h^2 + 2hk - k^2)}{3l^2 + 4c^2(h^2 + k^2 + hk)}.$$

$$\cos Z \text{ (basal)} = \frac{2c^2(h^2 + k^2 + 4hk) - 3l^2}{3l^2 + 4c^2(h^2 + k^2 + hk)}.$$

168. Angles. — The angles for some commonly occurring dihexagonal prisms with the first and second order prisms are given in the following table:

	$m(10\bar{1}0)$	$a(11\bar{2}0)$
$51\bar{6}0$	8° 57′	21° 3′
$41\bar{5}0$	10 53½	19 6½
$31\bar{4}0$	13 54	16 6
$52\bar{7}0$	16 6	13 54
$21\bar{3}0$	19 6½	10 53½
$32\bar{5}0$	23 24¾	6 35¼
$54\bar{9}0$	26 19¾	3 40¼

169. The Miller Axes and Indices. The forms of the hexagonal system were referred by Miller to a set of three equal oblique axes which were taken parallel to the edges of the unit positive rhombohedron of the species. Fig. 291 represents such a rhombohedron with the position of the Miller axes shown. This choice of axes for hexagonal forms has the grave objection that in several cases the faces of the same form are represented by two sets of different indices; for example the faces of the pyramid of the first order would have the indices, $100, 22\bar{1}, 010, \bar{1}22, 001, 2\bar{1}2$. This objection, however, disappears if the

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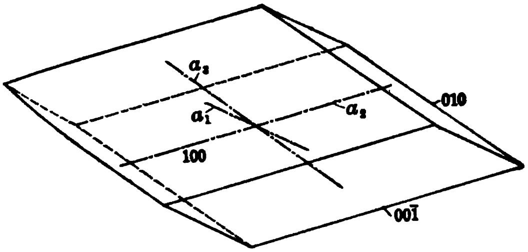

Miller axes and indices are used only for forms in the Rhombohedral Division, that is for forms belonging to classes which are characterized by a vertical axis of trigonal symmetry. It is believed, however, that the mutual relations of all the classes of both divisions of the hexagonal system among themselves (as also to the classes of the tetragonal system), both morphological and physical are best brought out by keeping throughout the same axes, namely those of Fig. 218, Art. **121**. The Miller method has, however, been adopted by a number of authors and consequently it is necessary to give the following brief description.

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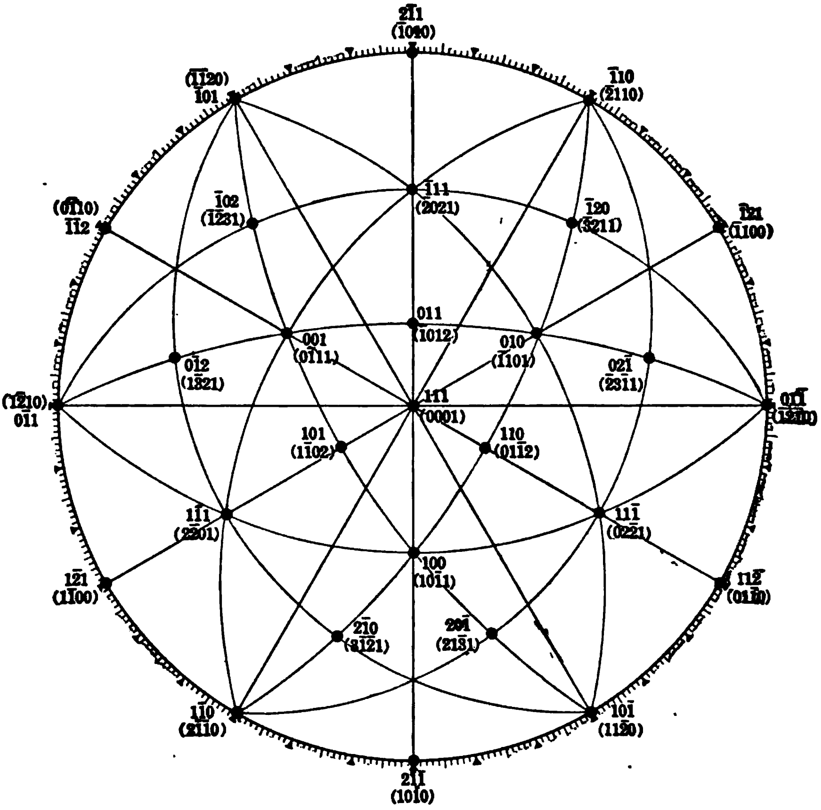

Miller and Miller-Bravais Indices Compared

Fig. 292 shows in stereographic projection the common hexagonal-rhombohedral forms with their Miller indices and in parentheses the corresponding indices when the faces are referred to the four axial system. It will be noted that the faces of the unit positive rhombohedron have the indices 100, 010, and 001 and those of the negative unit rhombohedron have $22\bar{1}$, $\bar{1}22$, $2\bar{1}2$. These two forms together give the faces of the hexagonal pyramid of the first order (see above). The hexagonal prism of the first order is represented by $2\bar{1}1$, etc., while the second order prism has $10\bar{1}$, etc. The dihexagonal pyramid has also two sets of indices (*hkl*) and (*efg*); of these the symbol (*hkl*) belongs to the positive scalenohedron and (*efg*) to the negative form. In this as in other cases it is true that $e = 2h + 2k - l$, $f = 2h - k + 2l$, $g = -h + 2k + 2l$. For example, the faces of the form $20\bar{1}$, etc., belong in the Rhombohedral Division of this system to the scalenohedron $(21\bar{3}1)$ while the complementary negative form would have the indices $52\bar{4}$, etc.

The relation between the Miller-Bravais and the Miller indices for any form can be obtained from the following expression, where (*hkil*) represents the first and (*pqr*) the second.

$$\frac{h}{p-q}=\frac{k}{p-r}=\frac{i}{r-p}=\frac{l}{p+q+r}.$$

The relation between the Miller indices for hexagonal forms and those of isometric forms should be noted. If we conceive of the isometric cube as a rhombohedron with interfacial angles of 90° and change the orientation so that the normal to the octahedral face (111) becomes vertical we get a close correspondence between the two. This will be seen by a comparison of the two stereographic projections, Figs. 292 and 125.

170. To determine, by plotting, the length of the vertical axis of a hexagonal mineral, given the position on the stereographic projection of the pole of a face with known indices. To illustrate this problem it is assumed that the mineral in question is beryl and that the position of the pole $p(10\bar{1}1)$ is known, Fig. 293. Let the three lines a_1, a_2, a_3 represent the horizontal axes with their unit lengths equalling the radius of the circle. Draw a line from the center of the projection through the pole *p*. Draw another line (which will be at right angles to the first) joining the ends of a_1 and $-a_3$. This will be parallel to a_2 and will represent the intercept of $p(10\bar{1}1)$ upon the plane of the horizontal axes. In order to plot the intercept of *p* upon the vertical axis construct in the upper left-hand quadrant of the figure a right-angle triangle the base of which shall be equal to O–P, the vertical side of which shall represent the *c* axis and the hypothenuse shall show the slope of the face and give its intercept upon the *c* axis. The direction of the hypothenuse is determined by locating the normal to *p* from the angle measured from the center of the projection to its pole. Since the face has been assumed to have an unit intercept on the vertical axis the distance O–M, which equals 0·49 (in terms of the length of the horizontal axes, which equals 1·00), gives the unit length of the *c* axis for beryl.

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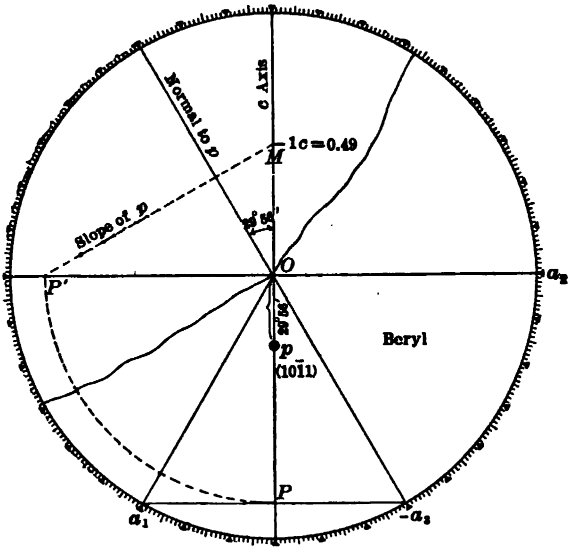

Determination of unit length of *c* axis, having given the position of $p(10\bar{1}1)$

171. To determine the indices of a face of a hexagonal form of a known mineral, given the position of its pole on the stereographic projection. In Fig. 294 it is assumed that the position of the pole *v* of a crystal face on calcite is known. To determine its indices, first draw a radial line through the pole and then erect a perpendicular to it, starting the line from the end of one of the horizontal axes. This line will represent the direction of the intersection of the crystal face with the horizontal plane and its relative intercepts on the horizontal axes will give the first three numbers of the parameters of the face, namely $1a_1$, $2a_2$, $\frac{2}{3}-a_3$. To determine the relative intercept on the *c* axis transfer the distance O–P to the upper left-hand quadrant of the figure, then having measured the angular distance between the center of the projection and *v* by means of the stereographic protractor draw the pole to the face in the proper position. Draw then a line at right angles to this pole starting from the point *P′*. This line gives the intercept of the face upon the line representing the vertical axis. In this case the intercept has a value of 1·7 when the length of the horizontal axes is taken as equal to 1·0. This distance 1·7 is seen to be twice the unit length of the *c* axis for calcite, 0·85. Therefore the parameters of the face in question upon the four axes are $1a_1$, $2a_2$, $\frac{2}{3}-a_3$, $2c$, which give $21\bar{3}1$ for the indices of the face *v*.

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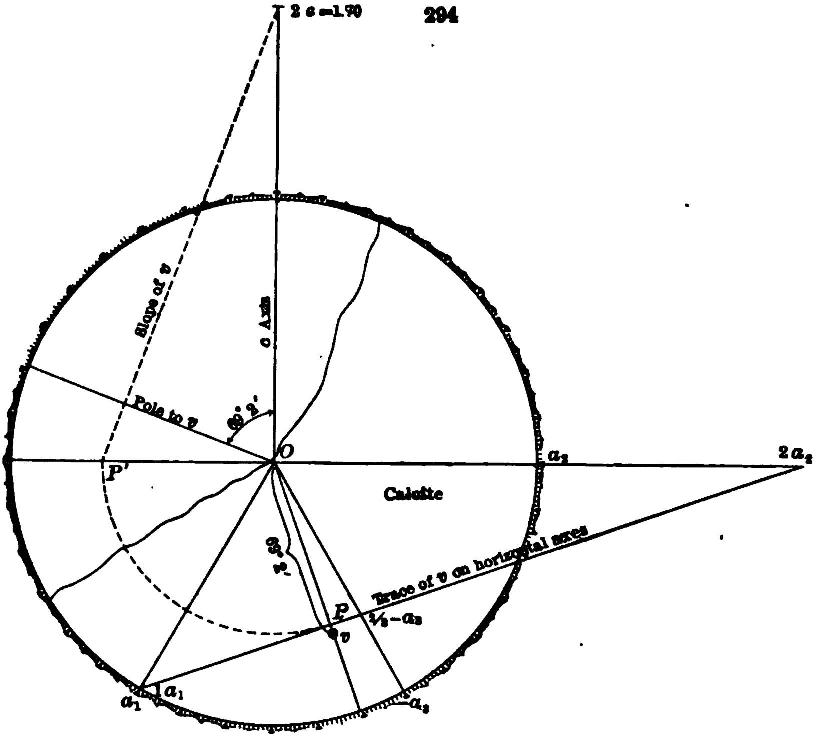

Determination of the indices for *v* on calcite

172. To determine, by plotting, the indices of hexagonal forms, given the position of their poles on the gnomonic projection. To illustrate this problem one sectant of the gnomonic projection of the important forms of beryl, Fig. 228, is reproduced in Fig. 295. The directions of the three horizontal axes, a_1, a_2 and a_3 are indicated by the heavy lines. From the poles of the faces perpendiculars are drawn to these three axes. It will be noted that the various intercepts made upon the axes by these lines have simple rational relations to each other. One of these intercepts is chosen as having the length of 1 (this length will be equivalent to the unit length of the *c* crystallographic axis, see below) and the others are then given in terms of it.

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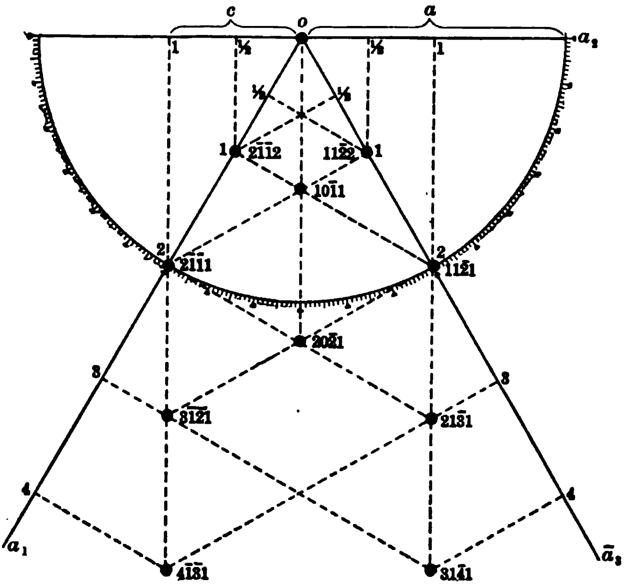

The indices of each face are obtained directly by taking these intercepts upon the three horizontal axes in their proper order and by adding a 1 as the fourth figure. If necessary clear of fractions, as in the case of the second order pyramid, $11\bar{2}2$.

173. To determine the axial ratio of a hexagonal mineral from the gnomonic projection of its forms. The gnomonic projection of the beryl forms, Fig. 295, may be used as an illustrative example. The radius of the fundamental circle, *a*, is taken as equal to the length of the horizontal axes and is given a value of 1. Then the length of the fundamental intercept of the lines dropped perpendicularly from the poles, *i.e.* the distance *c*, will equal the length of the *c* axis when expressed in terms of the length of *a*. In the case of beryl this ratio is $a : c = 1{\cdot}00 : 0{\cdot}499$. That this relationship is true can be proved in the same manner as in the case of the tetragonal system, see Art. **117**, p. 93.

IV. ORTHORHOMBIC SYSTEM

(Rhombic or Prismatic System)

174. Crystallographic Axes. — The *orthorhombic system* includes all the forms which are referred to three axes at right angles to each other, all of different lengths.

Any one of the three axes may be taken as the vertical axis, *c*. Of the two horizontal axes the longer is always taken as the *b* or macro-axis * and when orientated is parallel to the observer. The *a* or brachy-axis is the shorter of the two horizontal axes and is perpendicular to the observer. The length of the *b* axis is taken as unity and the lengths of the other axes are expressed in terms of it. The axial ratio for barite, for instance, is $a : b : c = 0{\cdot}815 : 1{\cdot}00 : 1{\cdot}31$. Fig. 296 shows the crystallographic axes for barite.

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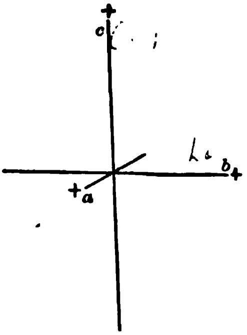

Orthorhombic Axes
(Barite)

1. NORMAL CLASS (25). BARITE TYPE

(Orthorhombic Bipyramidal or Holohedral Class)

175. Symmetry. — The forms of the *normal class* of the orthorhombic system are characterized by three axes of binary symmetry, which directions are coincident with the crystallographic axes. There are also three unlike planes of symmetry at right angles to each other in which lie the crystallographic axes.

The symmetry of the class is exhibited in the accompanying stereographic projection, Fig. 297. This should be compared with Fig. 91 (p. 53) and Fig. 167 (p. 77), representing the symmetry of the normal classes of the isometric and tetragonal systems respectively. It will be seen that while normal isometric crystals are developed alike in the three axial directions, those of the tetragonal type have a like development only in the direction of the two horizontal axes, and

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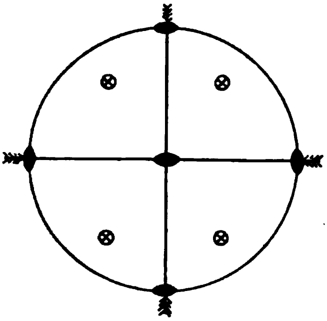

Symmetry of Normal Class
Orthorhombic System

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* The prefixes *brachy-* and *macro-* used in this system (and also in the triclinic system) are from the Greek words, *βραχύς*, *short*, and *μακρός*, *long*.

those of the orthorhombic type are unlike in the three even axial directions. Compare also Figs. 92 (p. 54), 171 (p. 78) and 298 (p. 122).

176. Forms. — The various forms possible in this class are as follows:

	Indices
1. Macropinacoid or *a*-pinacoid	(100)
2. Brachypinacoid or *b*-pinacoid	(010)
3. Base or *c*-pinacoid	(001)
4. Prisms	(*hk*0)
5. Macrodomes	(*h*0*l*)
6. Brachydomes	(0*kl*)
7. Pyramids	(*hkl*)

In general, as defined on p. 31, a *pinacoid* is a form whose faces are parallel to two of the axes, that is, to an axial plane; a *prism* is one whose faces are parallel to the vertical axis, but intersect the two horizontal axes; a *dome* * (or *horizontal prism*) is one whose faces are parallel to one of the horizontal axes, but intersect the vertical axis. A pyramid is a form whose faces meet all the three axes.

These terms are used in the above sense not only in the orthorhombic system, but also in the monoclinic and triclinic systems; in the last each form consists of two planes only.

177. Pinacoids. — The *macropinacoid* includes two faces, each of which is parallel both to the macro-axis *b* and to the vertical axis *c*; their indices are respectively 100 and $\bar{1}00$. This form is uniformly designated by the letter *a*, and is conveniently and briefly called the *a-face* or the *a-pinacoid*.

The *brachypinacoid* includes two faces, each of which is parallel both to the brachy-axis *a* and to the vertical axis *c*; they have the indices 010 and $0\bar{1}0$. This form is designated by the letter *b*; it is called the *b-face* or the *b-pinacoid*.

The *base* or *basal pinacoid* includes the two faces parallel to the plane of the horizontal axes, and having the indices 001 and $00\bar{1}$. This form is designated by the letter *c*; it is called the *c-face* or the *c-pinacoid*.

Each one of these three pinacoids is an open-form,† but together they make the so-called *diametral prism*, shown in Fig. 298, a solid which is the analogue of the cube of the isometric system. Geometrically it cannot be distinguished from the cube, but it differs in having the symmetry unlike in the three axial directions; this may be shown by the unlike physical character of the faces, *a*, *b*, *c*, for example as to luster, striations, etc.; or, again, by the cleavage. Further, it is proved at once by optical properties. This

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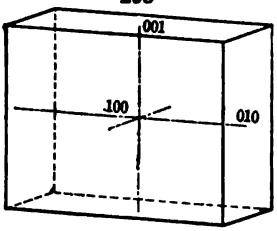
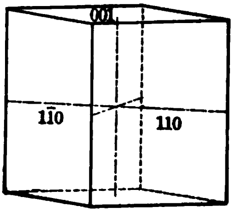


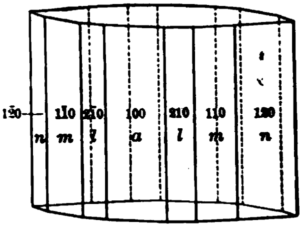
Macro-, Brachy- and Basal Pinacoids

299



Prism and Basal Pinacoid

300



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* From the Latin *domus*, because resembling the roof of a house; cf. Figs. 301, 302.

† See p. 30.

diametral prism, as just stated, has three pairs of unlike faces. It has three kinds of edges, four in each set, parallel respectively to the axes *a*, *b*, and *c*; it has, further, eight similar solid angles. In Fig. 298 the dimensions are arbitrarily made to correspond to the relative lengths of the chosen axes, but the student will understand that a crystal of this shape gives no information as to these values.

178. Prisms. — The prisms proper include those forms whose faces are parallel to the vertical axis, while they intersect both the horizontal axes; their general symbol is, therefore, (*hk*0). These all belong to one type of *rhombic prism*, in which the interfacial angles corresponding to the two unlike vertical edges have different values.

The *unit prism*, (110), is that form whose faces intersect the horizontal axes in lengths having a ratio corresponding to the accepted axial ratio of *a* : *b* for the given species; in other words, the angle of this unit prism fixes the unit lengths of the horizontal axes. This form is shown in combination with the basal pinacoid in Fig. 299; it is uniformly designated by the letter *m*. The four faces of the unit prism have the indices 110, $\bar{1}10$, $\bar{1}\bar{1}0$, $1\bar{1}0$.

There is, of course, a large number of other possible prisms whose intercepts upon the horizontal axes are not proportionate to their unit lengths. These may be divided into two classes as follows: *macroprisms*, whose faces lie between those of the macropinacoid and the unit prism, *brachyprisms* with faces between those of the brachypinacoid and the unit prism. A macroprism has the general symbol (*hk*0) in which $h > k$ and is represented by the form *l*(210), Fig. 300. A brachyprism has the general symbol (*hk*0) with $h < k$ and is represented by *n*(120), Fig. 300.

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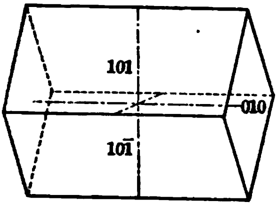
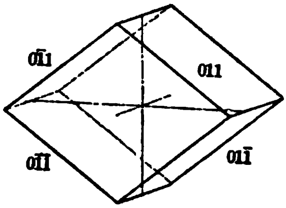


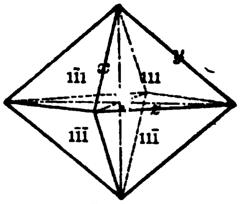
Macrodome and
Brachypinacoid

302



Brachydome
and Macropinacoid

303



Pyramid

179. Macrodomes, Brachydomes. — The *macrodomes* are forms whose faces are parallel to the macro-axis *b*, while they intersect the vertical axis *c* and the horizontal axis *a*; hence the general symbol is (*h*0*l*). The angle of the unit macrodome, (101), fixes the ratio of the axes *a* : *c*. This form is shown in Fig. 301 combined (since it is an open form) with the brachypinacoid.

In the macrodome zone between the base *c*(001) and the macropinacoid *a*(100) there may be a large number of macrodomes having the symbols, taken in the order named, (103), (102), (203), (101), (302), (201), (301), etc. Cf. Figs. 318 and 319 described later.

The *brachydomes* are forms whose faces are parallel to the brachy-axis, *a*, while they intersect the other axes *c* and *b*; their general symbol is (0*kl*). The angle of the unit brachydome, (011), which is shown with *a*(100) in Fig. 302, determines the ratio of the axes *b* : *c*.

The brachydome zone between *c*(001) and *b*(010) includes the forms (013), (012), (023), (011), (032), (021), (031), etc. Cf. Figs. 318 and 319.

Both sets of domes are often spoken of as *horizontal prisms*. The propriety of this expression is obvious, since they are in fact prisms in geometrical form; further, the choice of position for the axes which makes them domes, instead of prisms in the narrower sense, is more or less arbitrary, as already explained elsewhere.

180. Pyramids. — The pyramids in this system all belong to one type, the double *rhombic pyramid*, bounded by eight faces, each a scalene triangle. This form has three kinds of edges, x, y, z (Fig. 303), each set with a different interfacial angle; two of these angles suffice to determine the axial ratio. The symbol for this, the general form for the system, is (hkl).

The pyramids may be divided into three groups corresponding respectively to the three prisms just described, namely, unit pyramids, macropyramids, and brachypyramids.

The *unit pyramids* are characterized by the fact that their intercepts on the horizontal axes have the same ratio as those of the unit prism; that is, the assumed axial ratio $(a : b)$ for the given species. For them, therefore, the general symbol becomes (hhl).

There may be different unit pyramids on crystals of the same species with different intercepts upon the vertical axis, and these form a *zone* of faces lying between the base $c(001)$ and the unit prism $m(110)$. This zone would include the forms, (119), (117), (115), (114), (113), (112), (111). In the symbol of all of the forms of this zone $h = k$, and the lengths of the vertical axes are hence, in the example given, $\frac{1}{9}$, $\frac{1}{7}$, $\frac{1}{5}$, $\frac{1}{4}$, $\frac{1}{3}$, $\frac{1}{2}$ of the vertical axis c of the unit pyramid.

The *macropyramids* and *brachypyramids* are related to each other and to the unit pyramids, as were the macroprisms and brachyprisms to themselves and to the unit prism. Further, each vertical zone of macropyramids (or brachypyramids), having a common ratio for the horizontal axes (or of $h : k$ in the symbol), belongs to a particular macroprism (or brachyprism) characterized by the same ratio. Thus the macropyramids (214), (213), (212), (421), etc., all belong in a common vertical zone between the base (001) and the prism (210). Similarly the brachypyramids (123), (122), (121), (241), etc., fall in a common vertical zone between (001) and (120).

181. Illustrations. — The following figures of barite (304–311) give excellent illustrations of crystals of a typical orthorhombic species, and show also how the habit of one and the same species may vary. The axial ratio for this species is $a : b : c = 0·815 : 1 : 1·314$. Here d is the macrodome

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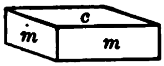

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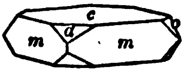

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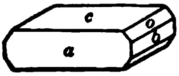

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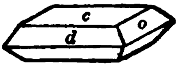

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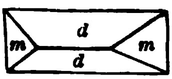

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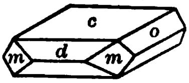

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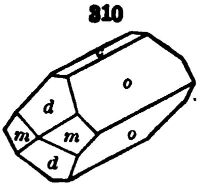

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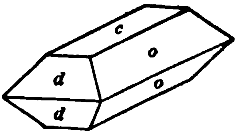
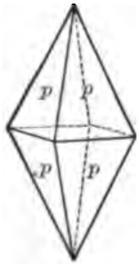


Barite Crystals

(102) and *o* the brachydome (011); *m* is, as always, the prism (110). Figs. 304–307 and 309 are described as tabular ‖ *c*; Fig. 308 is prismatic in habit in the direction of the macro-axis (*b*), and 310, 311 prismatic in that of the brachy-axis (*a*).

Figs. 312–314 of native sulphur show a series of crystals of pyramidal habit with the dome *n*(011), and the pyramids *p*(111), *s*(113). Note *n* truncates the terminal edges of the fundamental pyramid *p*. In general it should be remembered that a macrodome truncating the edge of a pyramid must have the same ratio of *h* : *l*; thus, (201) truncates the edge of (221), etc. Similarly of the brachydomes: (021) truncates the edge of (221), etc. Cf. Figs. 319–321.

312



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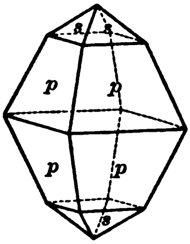
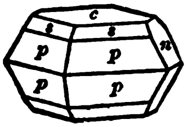
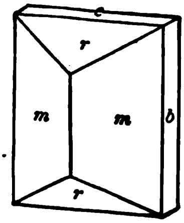


314



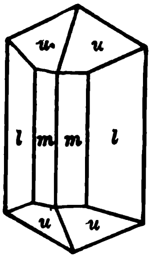
Sulphur Crystals

315



Staurolite

316



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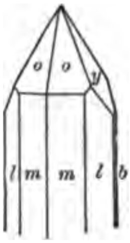

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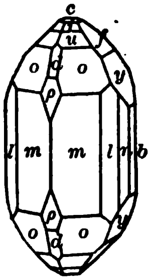
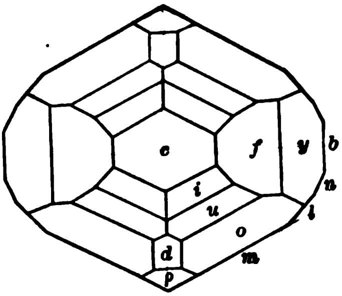


Figs. 316-318, Topaz

Again, Fig. 315, of staurolite, shows the pinacoids *b*(010), *c*(001), the prism *m*(110), and the macrodome *r*(101).

Figs. 316–318 are prismatic crystals of topaz. Here *m* is the prism (110); *l* and *n* are the prisms (120), (140); *d* and *ρ* are the macrodomes (201) and (401); *f* and *y* are the brachydomes (021) and (041); *i*, *u*, and *o* are the pyramids (223), (111), (221).

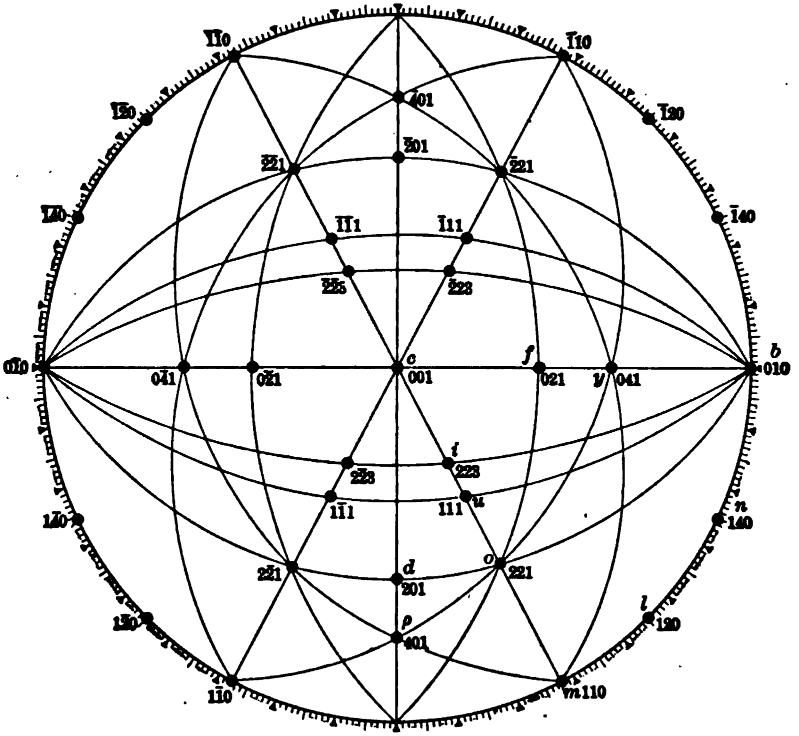
319



Topaz

182. Projections. — Basal, stereographic, and gnomonic projections are given in Figs. 319–320*a*, on pp. 125, 126, 127 for a crystal of the species topaz. Fig. 319 is the basal projection of the crystal shown in Fig. 318. Figs. 320 and 320*a* give the stereographic and gnomonic projections of these forms present upon it.

320



Stereographic Projection Topaz Crystal

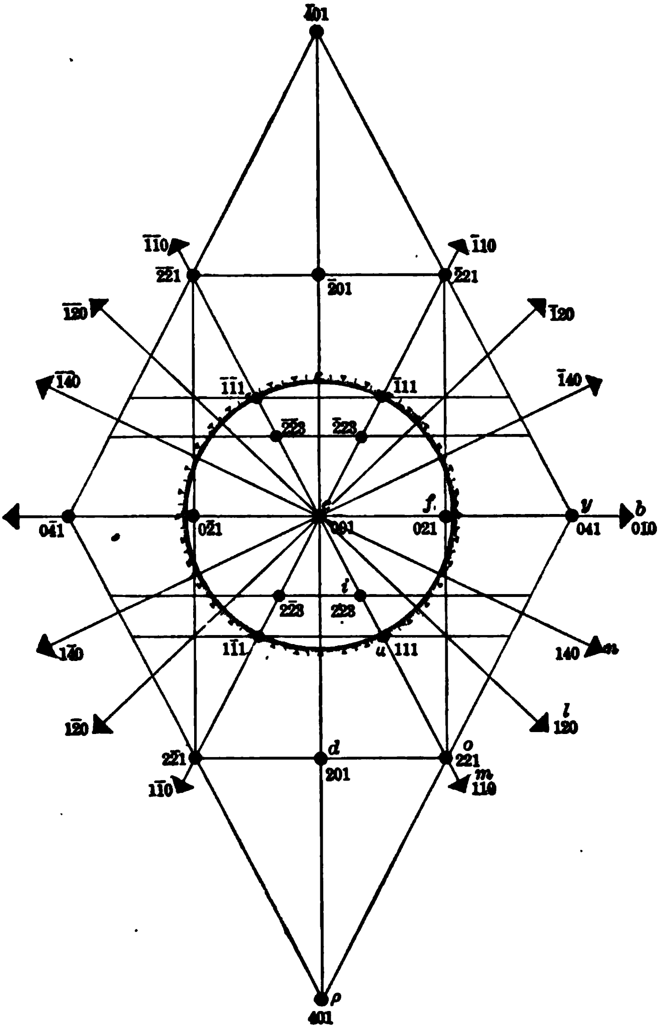
2. HEMIMORPHIC CLASS (26). CALAMINE TYPE

(*Orthorhombic Pyramidal Class*)

183. Class Symmetry and Typical Forms. — The forms of the *orthorhombic-hemimorphic* class are characterized by two unlike planes of symmetry and one axis of binary symmetry, the line in which they intersect; there is no center of symmetry. The forms are therefore hemimorphic, as defined in Art. 29. For example, if, as is usually the case, the vertical axis is made the axis of symmetry, the two planes of symmetry are parallel to the pinacoids *a*(100) and *b*(010). The prisms are then geometrically like those of the normal class, as are also the macropinacoid and brachypinacoid; but the two basal planes become independent forms, (001) and $(00\bar{1})$. There are also two macrodomes, (101) and $(10\bar{1})$, or in general $(h0l)$ and $(h0\bar{l})$; and similarly two sets, for a given symbol, of brachydomes and pyramids.

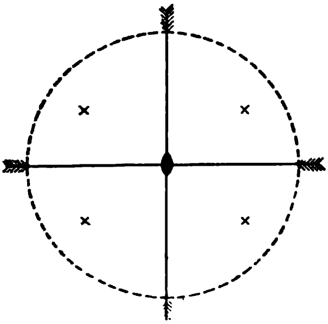
The general symmetry of the class is shown in the stereographic projec-

320



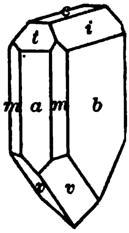
Gnomonic Projection Topaz Crystal

321



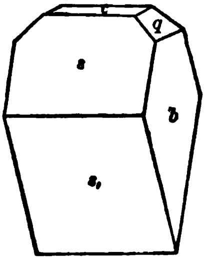
Symmetry of Hemimorphic Class

322



Calamine

323



Struvite

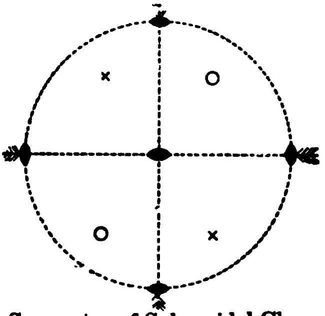
tion, Fig. 321. Further, Figs. 322, of calamine, and 323, of struvite, represent typical crystals of this class. In Fig. 322 the forms present are *t*(301), *i*(031), *v*($12\bar{1}$); in Fig. 323 they are *s*(101), s_1($10\bar{1}$), *q*(011).

3. SPHENOIDAL CLASS (27). EPSOMITE TYPE.

(*Orthorhombic Bisphenoidal Class*)

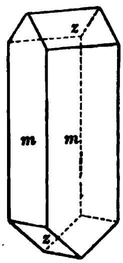
184. Symmetry and Typical Forms. — The forms of the remaining class of the system, the *orthorhombic-sphenoidal* class, are characterized by three unlike rectangular axes of binary symmetry which coincide with the crystallographic axes, but they have no plane and no center of symmetry (Fig. 324). The general form *hkl* here has four faces only, and the corresponding solid is a rhombic sphenoid, analogous to the sphenoid of the tetragonal system. The complementary positive and negative sphenoids are enantiomorphous. Fig. 325 represents a typical crystal, of epsomite, with the positive sphenoid, *z*(111). Other crystals of this species often show both positive and negative complementary forms, but usually unequally developed.

324



Symmetry of Sphenoidal Class

325



Epsomite

Mathematical Relations of the Orthorhombic System

185. Choice of Axes. — As explained in Art. **175**, the three crystallographic axes are fixed as regards direction in all orthorhombic crystals, but any one of them may be made the vertical axis, *c*; and of the two horizontal axes, which is the longer (*b*) and which the shorter (*a*) cannot be determined until it is decided which faces to assume as the fundamental, or unit, pyramid, prism, or domes.

The choice is generally so made, in a given case, as to best bring out the relation of the crystals of the species in hand to others allied to them in form or in chemical composition, or in both respects; or, so as to make the cleavage parallel to the fundamental form; or, as suggested by the common habit of the crystals, or other considerations.

186. Axial and Angular Elements. — The *axial elements* are given by the ratio of the lengths of the three axes in terms of the macro-axis, *b*, as unity. For example, with barite the axial ratio is

$$a : b : c = 0{\cdot}81520 : 1 : 1{\cdot}31359.$$

The *angular elements* are usually taken as the angles between the three pinacoids and the unit faces in the three zones between them. Thus, again for barite, these elements are

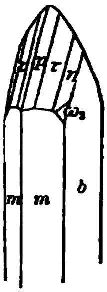
$$100 \wedge 110 = 39^\circ\ 11'\ 13'', \quad 001 \wedge 101 = 58^\circ\ 10'\ 36'', \quad 001 \wedge 011 = 52^\circ\ 43'\ 8''.$$

Two of these angles obviously determine the third angle as well as the axial ratio. The degree of accuracy to be attempted in the statement of the axial ratio depends upon the character of the fundamental measurements from which this ratio has been deduced. There is no good reason for giving the values of *a* and *c* to many decimal places if the probable error of the measurements amounts to many minutes. In the above case the measurements (by Helmhacker) are supposed to be accurate within a few seconds. It is convenient, however, to have the angular elements correct, say, within 10″, so that the calculated angles obtained from them will not vary from those derived direct from the measured angles by more than 30″ to 1′.

187. Calculation of the Axes. — The following simple relations (cf. Art. 48) connect the axes with the angular elements:

$$\tan(100 \wedge 110) = a, \quad \tan(001 \wedge 011) = c, \quad \tan(001 \wedge 101) = \frac{c}{a}$$

326



Stibnite

These equations serve to give either the axes from the angular elements, or the angular elements from the axes. It will be noted that the axes are not needed for simple purposes of calculation, but it is still important to have them, for example to use in comparing the morphological relations of allied species.

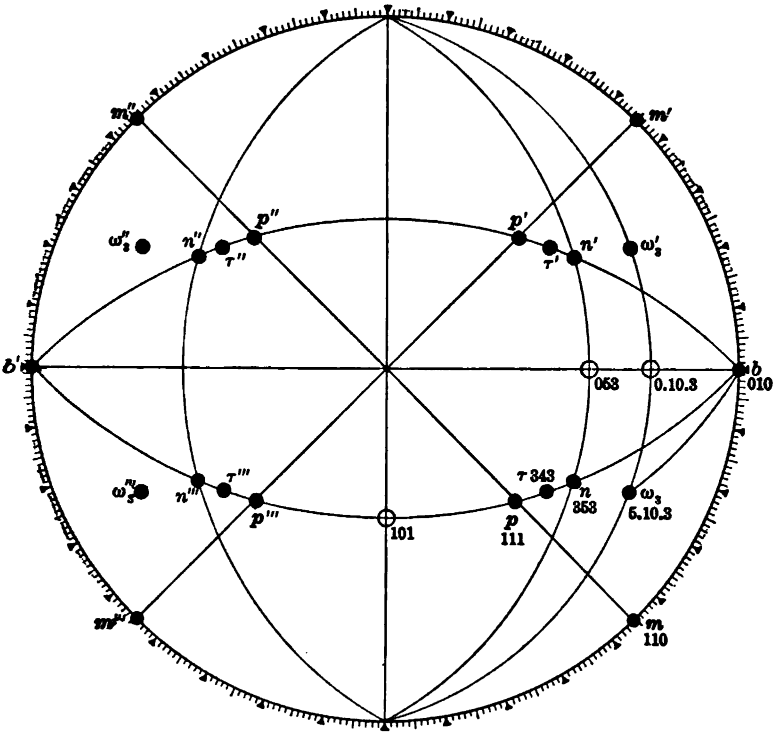
In practice it is easy to pass from the measured angles, assumed as the basis of calculation (or deduced from the observations by the method of least squares), to the angular elements, or from either to any other angles by the application of the tangent principle (Art. 49) to the pinacoidal zones, and by the solution of the right-angled spherical triangles given on the sphere of projection.

Thus any face *hkl* lies in the three zones, 100 and 0*kl*, 010 and *h*0*l*, 001 and *hk*0. For example, the position of the face 312 is fixed if the positions of two of the poles, 302, 012, 310, are known. These last are given, respectively, by the equations

$$\tan(001 \wedge 302) = \tfrac{3}{2} \times \tan(001 \wedge 101),$$

$$\tan(001 \wedge 012) = \tfrac{1}{2} \times \tan(001 \wedge 011) \quad \tan(100 \wedge 310) = \tfrac{1}{3} \times \tan(100 \wedge 110).$$

327



Stereographic Projection Stibnite Crystal

188. Example. — Fig. 326 represents a crystal of stibnite from Japan and Fig. 327 the stereographic projection of its forms, $p(111)$, $\tau(343)$, $\eta(353)$, $\omega_3(5{\cdot}10{\cdot}3)$, $m(110)$ and $b(010)$. On this the following measured angles were taken as fundamental:

$$\eta\eta' \ (353 \wedge \bar{3}53) = 55^\circ\ 1'\ 0'',$$
$$\eta\eta''' \ (353 \wedge 3\bar{5}3) = 99^\circ\ 39'\ 0''.$$

Hence, the angles 353 ∧ 010 = 40° 10½′ and 353 ∧ 053 = 27° 30½′ are known without calculation. The right-angled spherical triangle* 010·053·353 yields the angle (010 ∧ 053) and hence (001 ∧ 053); also the angle at 010, which is equal to (001 ∧ 101). But tan (001 ∧ 011) = ⅗ × tan (001 ∧ 053), and tan (001 ∧ 011) = c. Also, since tan (001 ∧ 101) = $\frac{c}{a}$, the axial ratio is thus known, and two of the angular elements.

The third angular element (001 ∧ 110) can be calculated independently, for the angle at 001 in the triangle 001·053·353 is equal to (010 ∧ 350) and tan (010 ∧ 350) × ⅗ = (010 ∧ 110), the complement of (100 ∧ 1̄10).

Then since tan (100 ∧ 110) = a, this can be used to check the value of a already obtained. The further use of the tangent principle with the occasional solution of a right-angled triangle will serve to give any desired angle from either the fundamental angles direct, or from the angular elements.

Again, the symbol of any unknown face can be readily calculated if two measured angles of tolerable accuracy are at hand. For example, for the face ω, suppose the measured angles to be

$$b\omega\ (010 \wedge hkl) = 30^\circ\ 15', \quad \omega\omega'\ (hkl \wedge \bar{h}kl) = 51^\circ\ 32'.$$

The solution of the triangle $b{\cdot}\omega{\cdot}0kl$ gives the angle (010 ∧ $0kl$) = 16° 25′ 20″, and

$$\frac{\tan\ (001 \wedge 0kl)}{\tan\ (001 \wedge 011)} = \frac{\tan 73^\circ\ 34\tfrac{2}{3}'}{\tan 45^\circ\ 30\tfrac{1}{2}'} = 3{\cdot}333+, = \frac{k}{l}\cdot$$

But the ratio of $k : l$ must be rational and the number derived agrees most closely with 10 : 3.

Again, the angle (001 ∧ $h0l$) may now be calculated from the same triangle and the value 59° 38¾′ obtained. From this the ratio of h to l is derived since

$$\frac{\tan\ (001 \wedge h0l)}{\tan\ (001 \wedge 101)} = \frac{\tan 59^\circ\ 38\tfrac{3}{4}'}{\tan 45^\circ\ 43\tfrac{1}{4}'} = 1{\cdot}665 = \frac{h}{l}\cdot$$

This ratio is nearly equal to 5 : 3, and the two values thus obtained give the symbol 5·10·3. If, however, from the triangle 001·$0kl$·ω, the angle at 001 is calculated, the value 26° 42¾′ is obtained, which is also the angle (010 ∧ $hk0$). From this the ratio $h : k$ is deduced, since

$$\frac{\tan\ (010 \wedge 110)}{\tan\ (010 \wedge hk0)} = \frac{\tan 45^\circ\ 12\tfrac{3}{4}'}{\tan 26^\circ\ 42\tfrac{3}{4}'} = 2{\cdot}002 = \frac{k}{h}\cdot$$

The value of $\frac{k}{h}$ is hence closely equal to 2; this combined with that first obtained $\left(\frac{k}{l} = \frac{10}{3}\right)$ gives the same symbol 5·10·3.

This symbol being more than usually complex calls for fairly accurate measurements. How accurate the symbol obtained is can best be judged by comparing the measured angles with those calculated from the symbol. For example, in the given case the calculated angles for $\omega(5{\cdot}10{\cdot}3)$ are $b\omega$(010 ∧ 5·10·3) = 30° 16′, $\omega\omega'$(5̄·10·3) = 51° 35′. The correctness of the value deduced is further established if it is found that the given face falls into prominent zones.

It will be understood further that the zonal relations, explained on pp. 45-47, play an important part in all calculations. For example, in Fig. 326, if the symbol of τ were unknown, it could be obtained from a single angle (as $b\tau$), since for this zone $h = l$.

189. Formulas. — Although it is not often necessary to employ formulas in calculations, a few are added here for sake of completeness. Here a and c in the formulas are the lengths of the two axes a and c.

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* The student in this as in every similar case should draw a projection, cf. Fig. 327 (not necessarily accurately constructed), to show, if only approximately, the relative position of the faces present.

(1) For the distance between the pole of any face P(*hkl*) and the pinacoids *a*, *b*, *c*, we have in general:

$$\cos^2 \mathrm{P}a = \cos^2 (hkl \wedge 100) = \frac{h^2c^2}{h^2c^2 + k^2a^2c^2 + l^2a^2};$$

$$\cos^2 \mathrm{P}b = \cos^2 (hkl \wedge 010) = \frac{k^2a^2c^2}{h^2c^2 + k^2a^2c^2 + l^2a^2};$$

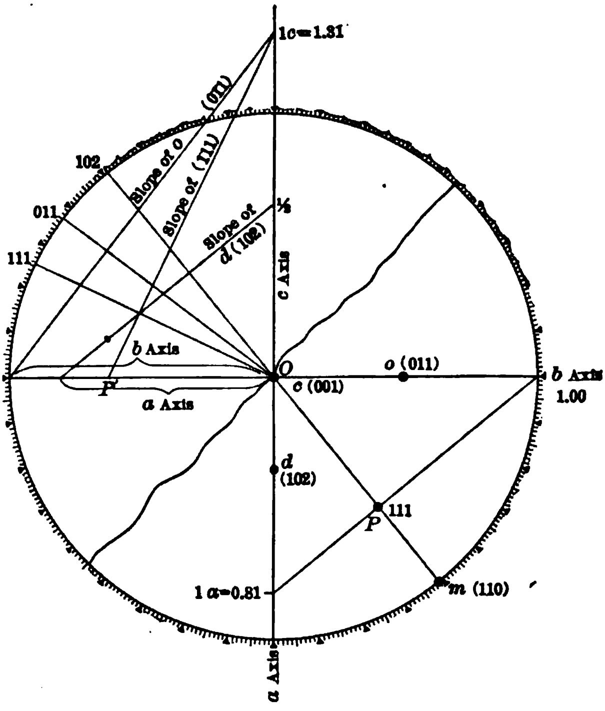
$$\cos^2 \mathrm{P}c = \cos^2 (hkl \wedge 001) = \frac{l^2a^2}{h^2c^2 + k^2a^2c^2 + l^2a^2}.$$

(2) For the distance (PQ) between the poles of any two faces (*hkl*) and (*pqr*)

$$\cos \mathrm{PQ} = \frac{hpc^2 + kqa^2c^2 + lra^2}{\sqrt{[h^2c^2 + k^2a^2c^2 + l^2a^2]\,[p^2c^2 + q^2a^2c^2 + r^2a^2]}}.$$

190. To determine, by plotting, the axial ratio of an orthorhombic crystal, having given the stereographic projection of its forms. In order to solve this problem it is necessary that the position of the pole of a pyramid face of known indices be given or the position of the faces of a prism and one dome or of both a macro- and a brachydome. For illustration it is assumed that a crystal of barite, such as represented in Fig. 305, has been measured on the goniometer and the poles of its faces plotted in the stereographic projection. The lower right-hand quadrant of this projection is shown in Fig. 328. The forms present are common ones on barite crystals and have been given the symbols, *m*(110), *d*(102), *o*(011), *c*(001). The ratio of *a* : *b* can be determined readily from the position of the pole *m*(110). A radial line is drawn to the pole of the face and then a perpendicular erected to it from the end of the line representing the *b* crystallographic axis. The intercept of this perpendicular on the line representing the *a* axis, when expressed in terms of the assumed unit length of the *b* axis, gives the length of *a*. It is to be noted that the fact that this line in the present case passes very nearly through the pole 111 is wholly accidental. The length of the vertical axis can be determined from the position of the pole of either *d*(102) or *o*(011). The construction used is given in the upper left-hand quadrant of the figure. If the brachydome, *o*(011), is used the sloping line that gives the inclination of the face is started from a distance on the horizontal line equivalent to the length of the *b* axis, or 1, and its intercept on the *c* axis will equal the unit length of that axis. If, however, the position of *d*(102) is used the base line of the triangle must be made equal to the unit length of the *a* axis as already established and the intercept on the *c* axis will equal ½ of the latter's unit length.

328

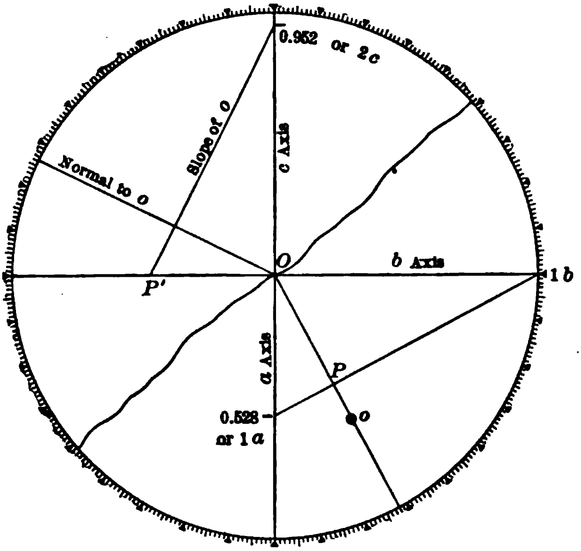


Determination of the Axial Ratio for Barite

The problem could have been wholly solved from the position of the pyramid face, 111, if that form had been present on the crystal. The construction in this case is also illustrated.

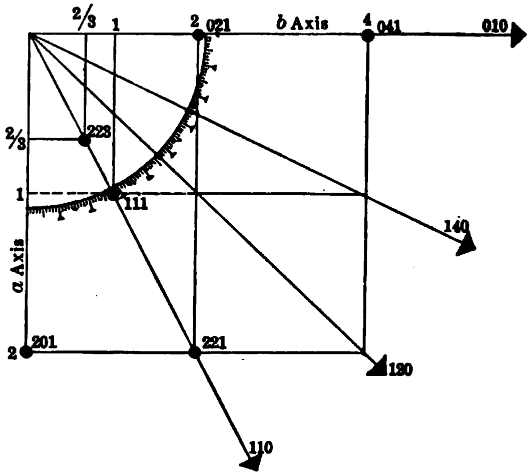
191. To determine, by plotting, the indices of a face upon an orthorhombic crystal, given the position of its pole upon the stereographic projection and the axial ratio of the mineral. To illustrate this problem it is assumed that the position of the pole in the stereographic projection of the face *o*, Fig. 329, upon a topaz crystal is known. First draw a radial line through the pole *o*. Next erect a perpendicular to this line, starting it from the distance selected as representing 1 on the *b* crystallographic axis. The intercept of this line upon the line representing the *a* axis when expressed in terms of the unit length of the *b* axis is 0·53. This is equivalent to the established unit length of the *a* axis and therefore the parameters of the face *o* on the horizontal crystallographic axes are 1*a*, 1*b*. Next the distance O–P is transferred into the upper left-hand quadrant of the figure. The position of the normal to the face is determined by measuring with a protractor the angular distance between O and *o*. The line giving the slope of the face is next drawn perpendicular to this normal and its intercept upon the line representing the vertical axis determined. This distance when expressed in terms of the length of the *b* axis is 0·95. This is twice the established length of the *c* axis (0·476) and consequently the third parameter of the face *o* is 2*c*. This gives the indices 221 for the face.

329



192. To determine, by plotting, the axial ratio of an orthorhombic crystal having given the gnomonic projection of its forms. To illustrate this problem the gnomonic projection of the crystal of topaz already given in Fig. 320*a* will be used. In Fig. 330 one quadrant of this projection is reproduced. From each pole lines are drawn perpendicular to the two lines representing the *a* and *b* crystallographic axes. It will be found that the intercepts made in this way upon the *a* axis have rational relations to each other. The same is true of the intercepts upon the *b* axis. The intercepts upon the two axes, however, are irrational in respect to each other. A convenient intercept upon each axis is chosen as 1 and the other intercepts upon that axis are then expressed in terms of this length. Of

330



course with a known mineral, whose forms have already had indices assigned to them, the intercept that shall be considered as 1 is fixed.

If we take r as equivalent to the radius of the fundamental circle of the projection, q as equal to the chosen intercept upon the b crystallographic axis and p that upon the a axis, then the axial ratio can be derived from the following expressions:

$$\frac{b}{c}=\frac{r}{q}; \quad \frac{a}{c}=\frac{r}{p}.$$

The proof of these relationships is similar to that already given under the Tetragonal System, Art. 117, p. 93.

193. To determine, by plotting, the indices of a face upon an orthorhombic crystal, given the position of its pole upon the gnomonic projection and the axial ratio of the mineral. The method of construction in this case is the reverse of that given in the problem above and is essentially the same as given under the Isometric and Tetragonal Systems, Arts. 84 and 118. In the case of an orthorhombic mineral the intercepts of the perpendiculars drawn from the pole of the face to the a and b axes must be expressed in each case in terms of the unit intercept on that axis. These values, p and q, can be determined from the equations given in the preceding problem.

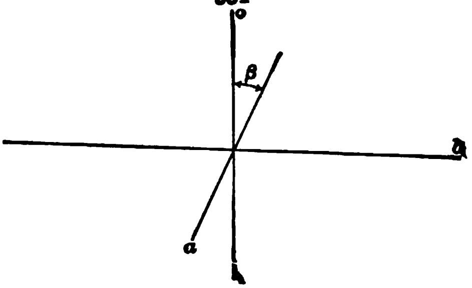
V. MONOCLINIC SYSTEM

(Oblique System)

194. Crystallographic Axes. — The *monoclinic system* includes all the forms which are referred to three unequal axes, having one of their axial inclinations oblique.

The axes are designated as follows: the inclined or clino-axis is a; the ortho-axis is b, the vertical axis is c. The acute angle between the axes a and c is represented by the letter β; the angles between a and b and b and c are right angles. See Fig. 331. When properly orientated the inclined axis, a, slopes down toward the observer, the b axis is horizontal and parallel to the observer and the c axis vertical.

331

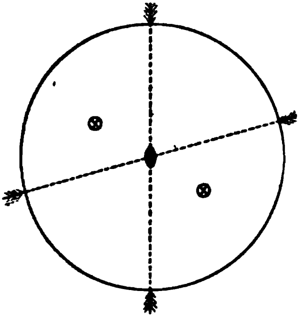


Crystal Axes of Orthoclase
$a:b:c=0{\cdot}66:1:0{\cdot}55.\ \beta=64°$

1. NORMAL CLASS (28). GYPSUM TYPE

(Prismatic or Holohedral Class)

332



Symmetry of Normal Class

195. Symmetry. — In the normal class of the monoclinic system there is one plane of symmetry and one axis of binary symmetry normal to it. The plane of symmetry is always the plane of the axes a and c, and the axis of symmetry coincides with the axis b, normal to this plane. The position of one axis (b) and that of the plane of the other two axes (a and c) is thus fixed by the symmetry; but the latter axes may occupy different positions in this plane. Fig. 332 shows the typical stereographic projection, projected on the plane of symmetry. Figs. 347, 348 are the projections of an actual crystal of epidote; here, as is usual, the plane of projection is normal to the prismatic zone.

196. Forms. — The various forms * belonging to this class, with their symbols, are given in the following table. As more particularly explained later, an orthodome includes two faces only, and a pyramid four only.

	Symbols
1. Orthopinacoid or *a*-pinacoid	(100)
2. Clinopinacoid or *b*-pinacoid	(010)
3. Base or *c*-pinacoid	(001)
4. Prisms	$(hk0)$
5. Orthodomes	$(h0l)$ $(\bar{h}0l)$
6. Clinodomes	$(0kl)$
7. Pyramids	(hkl) $(\bar{h}kl)$

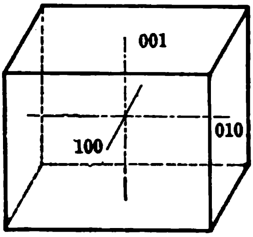
197. Pinacoids. — The pinacoids are the orthopinacoid, clinopinacoid, and the basal plane.

The *orthopinacoid*, (100), includes the two faces parallel to the plane of the ortho-axis *b* and the vertical axis *c*. They have the indices 100 and $\bar{1}00$. This form is designated by the letter *a*, since it is situated at the extremity of the *a* axis; it is hence conveniently called the *a-face* or *a-pinacoid*.

The *clinopinacoid*, (010), includes the two faces parallel to the plane of symmetry, that is, the plane of the clino-axis *a* and the axis *c*. They have the indices 010 and $0\bar{1}0$. The clinopinacoid is designated by the letter *b*, and is called the *b-face* or *b-pinacoid*.

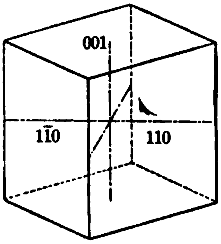
The *base* or *basal pinacoid*, (001), includes the two terminal faces, above and below, parallel to the plane of the axes *a*, *b*; they have the indices 001 and $00\bar{1}$. The base is designated by the letter *c*, and is often called the *c-face* or *c-pinacoid*. It is obviously inclined to the orthopinacoid, and the normal angle between the two faces $(100 \wedge 001)$ is the acute axial angle β.

333



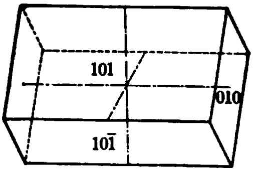
Ortho-, Clino- and Basal Pinacoids

334



Prism and Basal Pinacoid

335



Orthodomes and Clinopinacoid

The diametral prism, formed by these three pinacoids, taken together, Fig. 333, is the analogue of the cube in the isometric system. It is bounded by three sets of unlike faces; it has four similar vertical edges; also four similar edges parallel to the axis *a*, but the remaining edges, parallel to the axis *b*, are of two sets. Of its eight solid angles there are two sets of four each; the two above in front are similar to those below behind, and the two below in front to those above in behind.

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* On the general use of the terms pinacoid, prisms, domes, pyramids, see pp. 31, 122.

198. Prisms. — The prisms are all of one type, the oblique rhombic prism. They may be divided into three classes as follows: the *unit prism*, (110), designated by the letter *m*, shown in Fig. 334; the *orthoprisms*, (*hk*0), where $h > k$, lying between *a*(100) and *m*(110), and the *clinoprisms*, (*hk*0) where $h < k$, lying between *m*(110) and *b*(010). The orthoprisms and clinoprisms correspond respectively to the macroprisms and brachyprisms of the orthorhombic system, and the explanation on p. 123 will hence make their relation clear. Common cases of these prisms are shown in the figures given later.

199. Orthodomes. — The four faces parallel to the ortho-axis *b*, and meeting the other two axes, fall into two sets of two each, having the general symbols (*h*0*l*) and ($\bar{h}0l$). These forms are called *orthodomes;* they are strictly hemiorthodomes. For example, the unit orthodome (101) has the faces 101 and $\bar{1}0\bar{1}$; they would replace the two obtuse edges between *a*(100) and *c*(001) in Fig. 333. The other unit orthodome ($\bar{1}01$) has the faces $\bar{1}01$ and $10\bar{1}$, and they would replace the acute edges between *a*(100) and *c*(001). These two independent forms are shown together, with *b*(010), in Fig. 335.

Similarly the faces 201, $\bar{2}0\bar{1}$ belong to the form (201), and $\bar{2}01$, $20\bar{1}$ to the independent but complementary form ($\bar{2}01$).

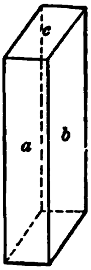
200. Clinodomes. — The *clinodomes* are the forms whose faces are parallel to the inclined axis, *a*, while intersecting the other two axes. Their general symbol is hence (0*kl*) and they lie between the base (001) and the clinopinacoid (010). Each form has four faces; thus for the unit clinodome these have the symbols, 011, $0\bar{1}1$, $0\bar{1}\bar{1}$, $01\bar{1}$. The form *n*(021) in Fig. 342 is a clinodome.

201. Pyramids. — The *pyramids* in the monoclinic system are all hemipyramids, embracing four faces only in each form, corresponding to the general symbol (*hkl*) This obviously follows from the symmetry; it is shown, for example, in the fact already stated that the solid angles of the diametral prism (Fig. 333, see above), which are replaced by these pyramids, fall into two sets of four each. Thus any general symbol, as (321), includes the two independent forms (321) and ($\bar{3}21$) with the faces

$$321,\quad 3\bar{2}1,\quad \bar{3}2\bar{1},\quad \bar{3}\bar{2}\bar{1},\quad \text{and}\quad \bar{3}21,\quad \bar{3}\bar{2}1,\quad 32\bar{1},\quad 3\bar{2}\bar{1}.$$

The pyramids may also be divided into three classes as *unit pyramids*, (*hhl*); *orthopyramids*, (*hkl*), when $h > k$; or *clinopyramids*, (*hkl*), when $h < k$. These correspond respectively to the three prisms already named. They are analogous also to the unit pryamids, macropyramids, and brachypyramids of the orthorhombic system, and the explanation given on p. 124, should serve to make their relations clear. But it must be remembered that each general symbol embraces two forms, (*hhl*) and ($\bar{h}kl$) with four faces each, as above explained.

336



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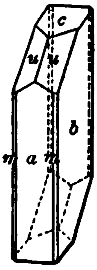

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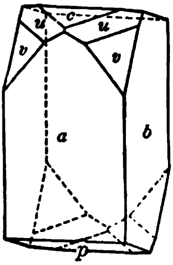
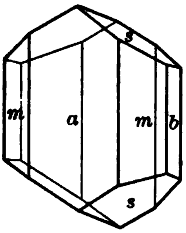


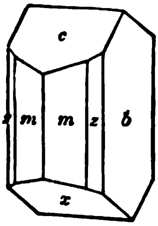
Pyroxene

339



202. Illustrations. — Figs. 336–339 of pyroxene ($a : b : c = 1{\cdot}092 : 1 : 0{\cdot}589$, $\beta = 74° = a(100) \wedge c(001)$) show typical monoclinic forms. Fig. 336 shows the diametral prism. Of the other forms, *m* is the unit prism (110); *p*($\bar{1}01$) is an orthodome; *u*(111), *v*(221), *s*($\bar{1}11$) are pyramids; for other figures see p. 475. Again, Figs. 340–342 represent common crystals of orthoclase ($a : b : c = 0{\cdot}659 : 1 : 0{\cdot}555$, $\beta = 64°$). Here *z*(130) is a prism; *x*($\bar{1}01$) and *y*($\bar{2}01$) are orthodomes; *n*(021) is a clinodome; *o*($\bar{1}11$) a pyramid. Since (Fig. 340) *c* and *x* happen to make nearly equal angles with the vertical edge of the prism *m*, the combination often simulates an orthorhombic crystal.

340



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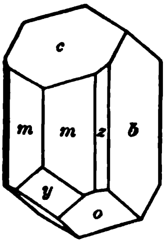

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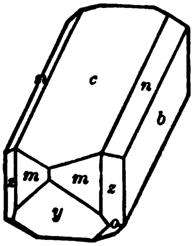
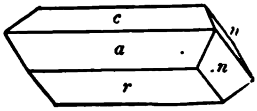


Orthoclase

Fig. 343 shows a monoclinic crystal, epidote, prismatic in the direction of the ortho-axis; the forms are *a*(100), *c*(001), *r*($\bar{1}01$) and *n*($\bar{1}11$). Fig. 344 of gypsum is flattened || *b*(010); it shows the unit pyramid *l*(111) with the unit prism *m*(110).

343



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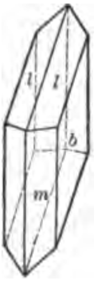

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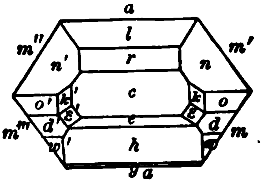
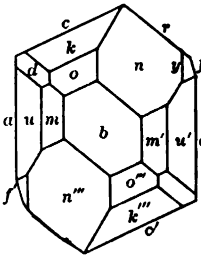


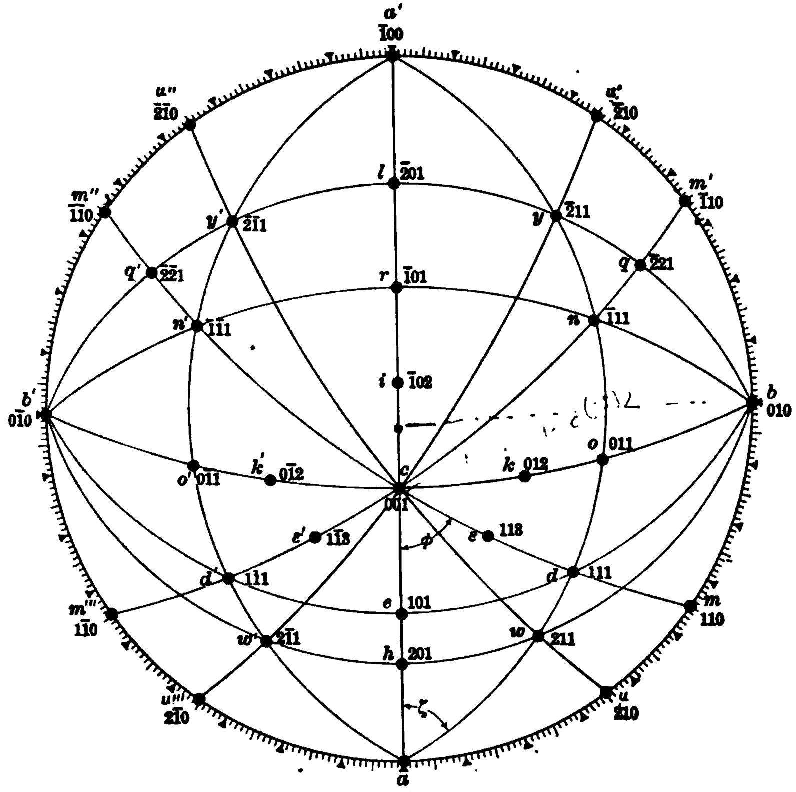
346



Epidote Gypsum Epidote

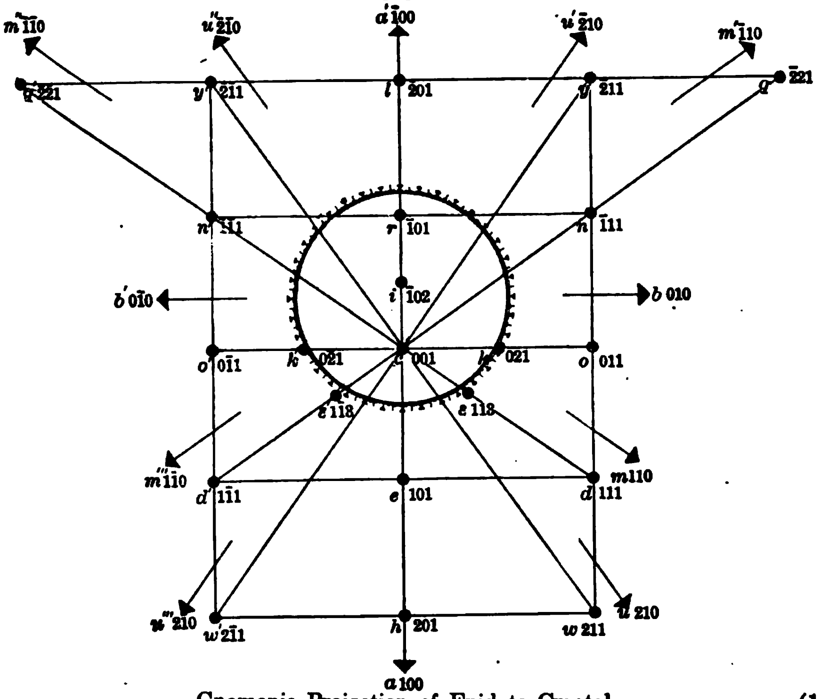
203. Projections. — Fig. 345 shows a projection of a crystal of epidote (cf. Fig. 897, p. 531) on a plane normal to the prismatic zone, and Fig. 346 one of a similar crystal on a plane parallel to *b*(010); both should be carefully studied, as also the stereographic and gnomonic projections of the same species, Figs. 347, 348. The symbols of the prominent faces are given in the latter figures.

347



Stereographic Projection of Epidote Crystal

348



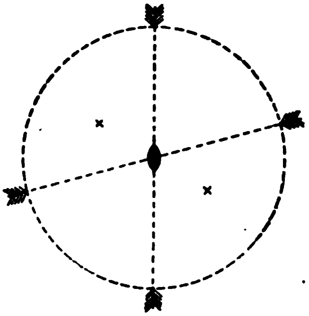
Gnomonic Projection of Epidote Crystal

2. HEMIMORPHIC CLASS (29). TARTARIC ACID TYPE

(*Sphenoidal Class*)

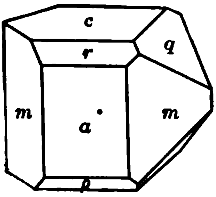
204. The *monoclinic-hemimorphic* class is characterized by a single axis of binary symmetry, the crystallographic axis *b*, but it has no plane of symmetry. It is illustrated by the stereographic projection (Fig. 349) made upon a plane parallel to *b*(010). Fig. 350 shows a common form of tartaric acid; sugar crystals also belong here. The hemimorphic character is distinctly shown in the distribution of the clinodomes and pyramids; corresponding to this the artificial salts belonging here often exhibit marked pyroelectrical phenomena.

349



Symmetry of Hemimorphic Class

350



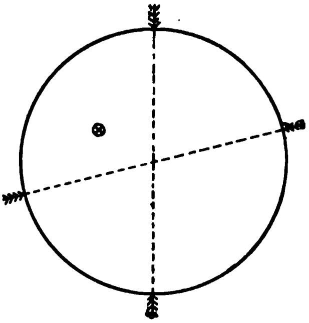
Tartaric Acid

3. CLINOHEDRAL CLASS (30). CLINOHEDRITE TYPE

(*Domatic or Hemihedral Class*)

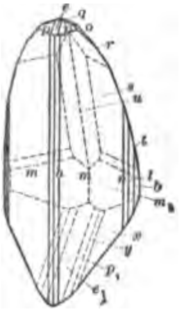
205. The *monoclinic-clinohedral* class is characterized by a single plane of symmetry, parallel to the clinopinacoid, *b*(010), but it has no axis of symmetry. This symmetry is shown in the stereographic projection made upon a plane parallel to *b*(010), Fig. 351. In this class, therefore, the forms parallel to the *b* axis, viz., *c*(001), *a*(100), and the orthodomes, are represented by a single face only. The other forms have each two faces, but it is to be noted that, with the single exception of the clinopinacoid *b*(010), the faces of a given form are never parallel to each other. The name given to the class is based on this fact.

351

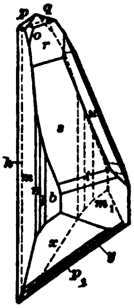


Symmetry of Clinohedral Class

352



353



Clinohedrite

Several artificial salts belong here in their crystallization, but the only known representative among minerals is the rare silicate, clinohedrite ($H_2CaZnSiO_5$),* a complex crystal of which is shown in two positions in Figs. 352, 353. As seen in these figures, the crystals of the group have a hemimorphic aspect with respect to their development in the direction of the vertical axis, although they cannot properly be called hemimorphic since this is not an axis of symmetry. The forms shown in Figs. 352 353 are as follows: pinacoid, *b*(010); prisms, *m*(110), $m_1(\bar{1}10)$, *h*(320), *n*(120), *l*(130); orthodomes, *e*(101), $e_1(\bar{1}0\bar{1})$; pyramids, *p*(111), $p_1(\bar{1}1\bar{1})$, $q(\bar{1}11)$, $r(\bar{3}31)$, $s(\bar{5}51)$, $t(\bar{7}71)$, $u(\bar{5}31)$, $o(\bar{1}31)$, $x(\bar{1}3\bar{1})$, $y(\bar{1}2\bar{1})$.

It is to be noted that crystals of the common species pyroxene (also of ægirite and titanite) occasionally show this habit in the distribution of their faces, but it is not certain that this may not be accidental.†

MATHEMATICAL RELATIONS OF THE MONOCLINIC SYSTEM

206. Choice of Axes. — It is repeated here (Art. **195**) that the fixed position of the plane of symmetry establishes the direction of the plane of the *a* and *c* crystallographic axes and also of the axis *b* which is the symmetry axis and lies at right angles to this plane. The *a* and *c* axes, however, may have varying positions in the symmetry plane according to which faces are taken as the pinacoids *a*(100) and *c*(001), and which the unit pyramid, prism, or domes.

207. Axial and Angular Elements. — The *axial elements* are the *lengths* of the axes *a* and *c* in terms of the unit axis *b*, that is, the axial ratio, with also the acute angle of inclination of the axes *a* and *c*, called *β*. Thus for orthoclase the axial elements are:

$$a : b : c = 0{\cdot}6585 : 1 : 0{\cdot}5554 \quad \beta = 63^\circ\ 56\tfrac{3}{4}'.$$

The *angular elements* are usually taken as the angle (100 ∧ 001) which is equal to the angle *β*; also the angles between the three pinacoids 100, 010, 001, respectively, and the unit prism 110, the unit orthodome (101 or $\bar{1}01$) and the unit clinodome 011. Thus, again, for orthoclase, the angular elements are:

$$001 \wedge 100 = 63^\circ\ 56\tfrac{3}{4}', \quad 100 \wedge 110 = 30^\circ\ 36\tfrac{1}{2}'.$$
$$001 \wedge \bar{1}01 = 50^\circ\ 16\tfrac{1}{2}', \quad 001 \wedge 011 = 26^\circ\ 31'.$$

208. The mathematical relations connecting axial and angular elements are given in the following equations in which *a*, *b*, and *c* represent the unit lengths of the respective crystallographic axes.

$$a = \frac{\tan\,(100 \wedge 110)}{\sin\beta} \quad \text{or} \quad \tan\,(100 \wedge 110) = a\,.\sin\beta; \tag{1}$$

$$c = \frac{\tan\,(001 \wedge 011)}{\sin\beta} \quad \text{or} \quad \tan\,(001 \wedge 011) = c\,.\sin\beta; \tag{2}$$

$$\left.\begin{aligned} c &= \frac{a\,.\tan\,(001 \wedge 101)}{\sin\beta - \cos\beta\,.\tan\,(001 \wedge 101)} \quad \text{or} \quad \tan\,(001 \wedge 101) = \frac{c\sin\beta}{a + c\,.\cos\beta}, \\ c &= \frac{a\,.\tan\,(001 \wedge \bar{1}01)}{\sin\beta + \cos\beta\,.\tan\,(001 \wedge \bar{1}01)} \quad \text{or} \quad \tan\,(001 \wedge \bar{1}01) = \frac{c\sin\beta}{a - c\,.\cos\beta}. \end{aligned}\right\} \tag{3}$$

These relations may be made more general by writing in the several cases —

in (1) *hk*0 for 110 and $\frac{k}{h}a$ for *a*; in (2) 0*kl* for 011 and $\frac{k}{l}c$ for *c*;

in (3) *h*0*l* for 101 and $\frac{h}{l}c$ for *c*.

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* Penfield and Foote, Am. J. Sc., **5**, 289, 1898.

† See G. H. Williams, Am. J. Sc., **34**, 275, 1887, **38**, 115, 1889.

Also

$$\frac{c}{a} = \frac{\sin\,(001 \wedge 101)}{\sin\,(100 \wedge 101)} = \frac{\sin\,(001 \wedge \bar{1}01)}{\sin\,(\bar{1}00 \wedge \bar{1}01)},$$

and more generally

$$\frac{h}{a} \cdot \frac{c}{l} = \frac{\sin\,(001 \wedge h0l)}{\sin\,(100 \wedge h0l)} = \frac{\sin\,(001 \wedge \bar{h}0l)}{\sin\,(\bar{1}00 \wedge \bar{h}0l)}.$$

Note also that

$$\tan \phi = a \qquad \text{and} \qquad \tan \zeta = c,$$

where ϕ is the angle (Fig. 347) between the zone-circles (001, 100) and (001, 110); also ζ is the angle between (100, 001) and (100, 011).

All the above relations are important and should be thoroughly understood.

209. The problems which usually arise have as their object either the deducing of the axial elements, *i.e.*, the angle β and the values of a and c in terms of $b(= 1)$, from three measured angles, or the finding of any required interfacial angles from these elements or from the fundamental angles.

The simple relations of the preceding article connect the angular and axial elements, and beyond this all ordinary problems can be solved * either by the solution of spherical triangles on the sphere of projection, or by the aid of the cotangent (and tangent) relation.

It is to be noted, in the first place, that all great circles on the sphere of projection (see the stereographic projection, Fig. 347) from 010 cut the zone circle 100, 001, $\bar{1}00$ at right angles, but those from 100 cut the zone circles 010, 001, $0\bar{1}0$ obliquely, as also those from 001 cutting the zone circle 100, 010, $\bar{1}00$.

210. Tangent and Cotangent Relations. — The simple *tangent relation* holds good for all zones from 010 to any pole on the zone circle 100, 001, $\bar{1}00$; in other words, for the prisms, clinodomes, and also zones of pyramids in which the ratio of $h : l$ is constant (from 001 to $h0l$ or to $\bar{h}0l$). Thus it is still true, as in the orthorhombic system, that the tangents of the angles of the prisms 210, 110, 120, 130 from 100 are in the ratio of ½ : 1 : 2 : 3, or, more generally, that

$$\frac{\tan\,(100 \wedge hk0)}{\tan\,(100 \wedge 110)} = \frac{k}{h} \quad \text{or} \quad \frac{\tan\,(010 \wedge hk0)}{\tan\,(010 \wedge 110)} = \frac{h}{k}.$$

Also for the clinodomes the tangents of the angles of 012, 011, 021 from 001 are in the ratio of ½ : 1 : 2, etc. A similar relation holds for the tangents of the angles of pyramids in the zones mentioned, as 121, 111, 212, etc.

For zones other than those mentioned as from 100 to a clinodome, or from 001 to a prism, the more general *cotangent formula* given in Art. **49** must be employed. This relation is simplified for certain common cases.

For any zone starting from 001, as the zone 001, 100, or 001, 110, or 001, 210, etc.; if two angles are known, viz., the angles between 001 and those two faces in the given zone which fall (1) in the zone 010, 101, and (2) in the prismatic zone 010, 100; then the angle between 001 and any other face in the given zone can be calculated.

Thus,

$$\begin{array}{llll} \text{Let} & 001 \wedge 101 = PQ & \text{and} & 001 \wedge 100 = PR, \\ \text{or “} & 001 \wedge 111 = PQ & \text{“} & 001 \wedge 110 = PR, \\ \text{or “} & 001 \wedge 212 = PQ & \text{“} & 001 \wedge 210 = PR, \text{ etc.} \end{array}$$

Then for these, or any similar cases, the angle (PS) between 001 and any face in the given zone (as 201, or 221, or 421, etc., or in general $h0l$, hhl, etc.) is given by the equation

$$\frac{\cot PS - \cot PR}{\cot PQ - \cot PR} = \frac{l}{h}.$$

For the corresponding zones from 001 to $\bar{1}00$, to $\bar{1}10$, to $\bar{2}10$, etc., the expression has the same value; but here

$$\begin{array}{lllll} & PQ = 001 \wedge \bar{1}01, & PR = 001 \wedge \bar{1}00, & PS = 001 \wedge \bar{h}0l, \\ \text{or} & \quad\;\; 001 \wedge \bar{1}11, \text{ etc.,} & \quad\;\; 001 \wedge \bar{1}10, \text{ etc.,} & \quad\;\; 001 \wedge \bar{h}hl, \text{ etc.} \end{array}$$

---

* The general formulas, from which it is possible to calculate directly the angles between any face and the pinacoids, or the angle between any two faces whatever, are so complex as to be of little value.

If, however, 100 is the starting-point, and

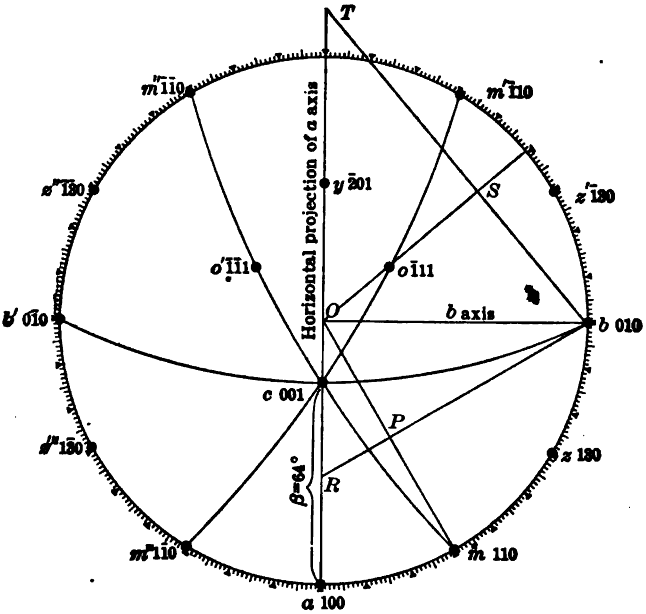
$$100 \wedge 101 = PQ \qquad 100 \wedge 001 = PR,$$
$$\text{or } 100 \wedge 111 = PQ, \qquad 100 \wedge 011 = PR, \text{ etc.,}$$

then the relation becomes

$$\frac{\cot PS - \cot PR}{\cot PQ - \cot PR} = \frac{h}{l}$$

211 To determine, by plotting, the axial elements of a monoclinic crystal, given the stereographic projection of its forms. As an example of this problem it is assumed that an orthoclase crystal similar to the one shown in Fig 341 has been measured and the poles of its faces located on the stereographic projection, Fig. 354. The inclination of the *a* axis or the angle β is given directly by measuring, by means of the stereographic protractor, the angular distance between the poles of *a*(100) and *c*(001). In the present case the *a*(100) form does not actually occur on the crystal. β is measured as 64°. If the base is not present upon the crystal it will be usually possible to locate its position by means of some zone circle on which it must lie In the present case the great circle of the zone of $m'(\bar{1}10)$, $o(\bar{1}11)$, $m'''(1\bar{1}0)$ will cross the front to back line (zone of the orthodomes) at the point of the pole to the base.

354



Determination of Axial Elements of Orthoclase from Stereographic Projection

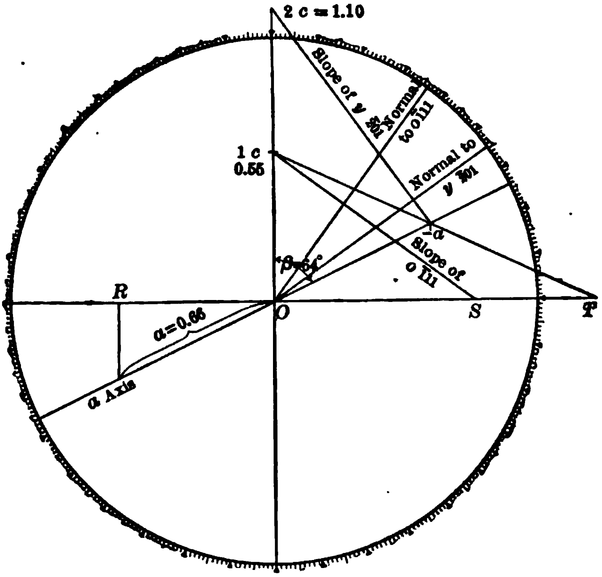
The ratio between the lengths of the *a* and *b* axes can be readily determined from the position of the pole, *m*(110). Draw the radial line O–P from the center of the projection to *m*(110). From the end of the *b* axis draw a line at right angles to O–P. This represents the intersection of the prism face with the horizontal plane and the distance O–R gives the intercept of the prism upon the *horizontal projection of the a axis*. The distance O–R therefore is not the unit length of the *a* axis but is that distance foreshortened somewhat because of the inclination of that axis. The construction by which the true length of the *a* axis is obtained is shown in Fig. 355. The line R–O–S–T represents the horizontal projection of the *a* axis upon which the distance O–R is transferred from Fig. 354. As the prism face is vertical its intercept upon the *a* axis can be found by dropping a perpendicular from R to intersect the line which represents the *a* axis. The inclination of this last line is found by use of the angle β, which has been already determined. The length of the *a* axis when expressed in terms of the *b* axis (1·00) was found to be 0·66.

The length of the *c* axis can be found best from the inclination of the *y*($\bar{2}01$) face. This face will intersect the negative end of the *a* axis and the upper end of the *c* axis at either $\frac{1}{2}a$, 1*c* or 1*a*, 2*c*. The angle between the center of the projection, O, Fig. 354, and the pole *y* is measured by means of the stereographic protractor. From this angle the position of the normal to *y*, as shown in Fig. 355, is determined. The line representing the slope of the face is drawn at right angles to this normal, starting from the negative unit length of the inclined *a* axis. The intercept on the *c* axis was found to be equal to 1·11, which, as it is equal to 2*c*, would give the unit length of the *c* axis as, 0·55.

The length of the *c* axis could also be determined from the inclination of the pyramid face, *o*($\bar{1}11$). The method of construction would be similar to that described in the problem below.

212. To determine the indices of a face upon a monoclinic crystal, having given the position of its pole upon the stereographic projection and the axial elements of the mineral. The pyramid face *o* on orthoclase will be used to illustrate the problem. First, see Fig. 354, a radial line is drawn through the pole *o* and a perpendicular S–T erected to it, starting from the unit length of the *b* axis. It is to be noted that the point T is the intersection of the face *o* with the horizontal projection of the *a* axis Transfer the distance O–S to the horizontal line in Fig. 355 and locate the position of the normal to *o* by the angle, Fig. 354, between O and *o*. The line giving the slope of the face can then be drawn from the point S (Fig. 355) perpendicular to the normal. This line intersects the line representing the vertical axis at a distance equal to its unit length. Two points of intersection of the pyramid face with the plane of the *a* and *c* axes have now been determined, namely 1*c* and T. A line joining these two points will give the intersection of the two planes and the point where it crosses the line representing the *a* axis will therefore give the intercept of the pyramid upon that axis. This is also found to be at the unit length and therefore the indices of *o* must be $\bar{1}11$.

355



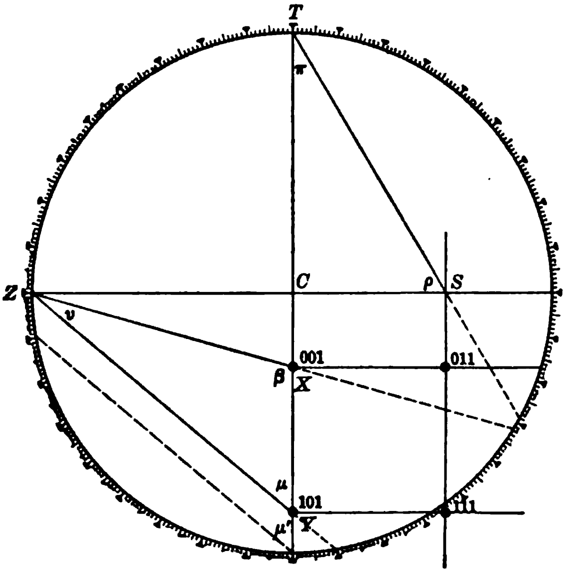
Determination of Axial Elements, etc. of Orthoclase

213. To determine, by plotting, the axial elements of a monoclinic crystal, having given the gnomonic projection of its forms. The construction by which this problem is solved is shown in Fig. 356. The poles of the unit forms (101), (011), (001) and (111) are located (in this case for pyroxene) and the zonal lines drawn. The angle β is complementary to the angle from the center of the projection to 001. This can be measured directly by means of the gnomonic tangent scale. Then construct the triangles CST and XYZ. The angles ρ and π, and υ and ν are measured. This can most easily be done by means of the divided circle and the fact that an angle at the circumference of a circle is measured by one half its subtended arc. The following relations will then yield the axial ratio.

$$\frac{b}{c} = \frac{\sin \rho}{\sin \pi}; \quad \frac{a}{c} = \frac{\sin \upsilon}{\sin \nu}.$$

For the proof of these relations see the explanation of the more general case under the triclinic system, Art. 227, p. 152.

356



Determination of Axial Elements of Pyroxene from Gnomonic Projection

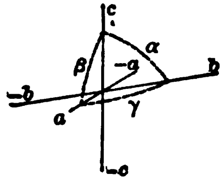
214. To determine, by plotting, the indices of a face on a monoclinic crystal, having given the position of its pole upon the gnomonic projection. There is no essential difference between the orthorhombic and monoclinic systems in the determination of indices from the gnomonic projection. The intercepts of perpendiculars from the poles of the faces upon the front to back and left to right zonal lines running through the pole of $c(001)$ give directly the first two numbers of the indices. The gnomonic projection of the epidote crystal already given (Fig. 348) will serve to illustrate this problem.

VI. TRICLINIC SYSTEM

(*Anorthic System*)

215. Crystallographic Axes. — The *triclinic system* includes all the forms which are referred to three unequal axes with all their intersections oblique. When orientated in the customary manner one axis has a vertical position and is called the *c* axis (cf. Fig. 357), a second axis lies in the front-to-back plane, sloping down toward the observer, and is called the *a* axis. The remaining axis is designated as the *b* axis. Usually the *a* and *b* axes are so chosen that the *a* axis is the shorter and, like in the orthorhombic system, is sometimes called the brachy-axis. In that case the *b* axis is longer and is known as the macro-axis. But this is not invariably true; thus with rhodonite the ratio of $a : b = 1{\cdot}073 : 1$. The angle between the axes *b* and *c* is called α, that between *a* and *c* is β, and that between *a* and *b* is γ (Fig. 357). It is to be noted that there is no necessary relation between the values of α, β, and γ, any one may be greater or less than 90°; this is determined by the choice of the fundamental forms.

357



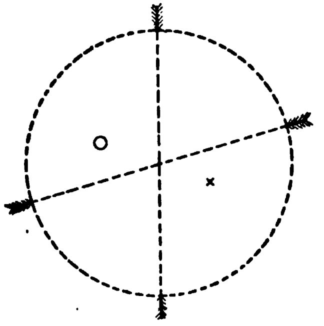
Triclinic Axes

1. NORMAL CLASS (31). AXINITE TYPE

(*Holohedral or Pinacoidal Class*)

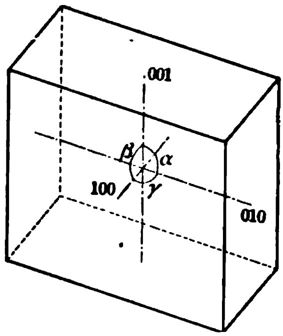
216. Symmetry. — The normal class of the triclinic system is characterized by a center of symmetry, the point of intersection of the three axes, but there is no plane and no axis of symmetry. This symmetry is shown in the accompanying stereographic projection (Fig. 358).

358



Symmetry of Normal Class

359



Triclinic Pinacoids

217. Forms. — Each form of the class includes two faces, parallel to one another and symmetrical with reference to the center of symmetry. This is true as well of the form with the general symbol (*hkl*) as of one of the special forms, as, for example, the *a*-pinacoid (100).

Hence, as shown in the following table, the four prismatic faces 110, $\bar{1}10$, $\bar{1}\bar{1}0$, $1\bar{1}0$ include two forms, namely, 110, $\bar{1}\bar{1}0$, and $\bar{1}10$, $1\bar{1}0$. The same is true of the domes. Further, any eight corresponding pyramidal faces, as, for example, 111, $\bar{1}11$, $\bar{1}\bar{1}1$, $1\bar{1}1$, $11\bar{1}$, $\bar{1}1\bar{1}$, $\bar{1}\bar{1}\bar{1}$, $1\bar{1}\bar{1}$ belong to four distinct forms, namely, 111, $\bar{1}\bar{1}\bar{1}$; $\bar{1}11$, $1\bar{1}\bar{1}$; $\bar{1}\bar{1}1$, $11\bar{1}$; $1\bar{1}1$, $\bar{1}1\bar{1}$, and similarly in general.

The various types of forms are given in the following table:

	Indices
Macropinacoid or *a*-pinacoid	(100)
Brachypinacoid or *b*-pinacoid	(010)
Base or *c*-pinacoid	(001)
Prisms	$(hk0)$ $(h\bar{k}0)$
Macrodomes	$(h0l)$ $(\bar{h}0l)$
Brachydomes	$(0kl)$ $(0\bar{k}l)$
Pyramids	(hkl) $(\bar{h}kl)$ $(\bar{h}\bar{k}l)$ $(h\bar{k}l)$

In the above table it is assumed that the axial ratio is such that $a < b$. If the opposite were true the names brachy- and macro- would be interchanged.

218. The explanations given under the two preceding systems make it unnecessary to discuss in detail the various forms individually, except as illustrated in the case of crystals belonging to certain typical triclinic species.

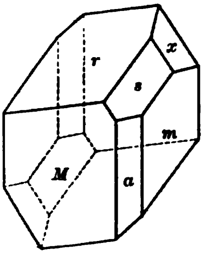
It may be mentioned, however, that Fig. 359 shows the *diametral prism*, which is bounded by three sets of unlike faces, the pinacoids *a*, *b*, and *c*. This is the analogue of the cube of the isometric system, but here the like faces, edges, and solid angles include only a given face, edge, and angle, and that opposite to it.

219. Illustrations. — A typical triclinic crystal is shown in Fig. 360 of axinite. Here $a(100)$ is the macropinacoid; $m(110)$ and $M(1\bar{1}0)$ the two unit prisms; $s(201)$ a macrodome, and $x(111)$ and $r(1\bar{1}1)$ two unit pyramids. The axial ratio is as follows:

$$a : b : c = 0{\cdot}49 : 1 : 0{\cdot}48,\ \alpha = 82^\circ\ 54',\ \beta = 91^\circ\ 52',\ \gamma = 131^\circ\ 32'.$$

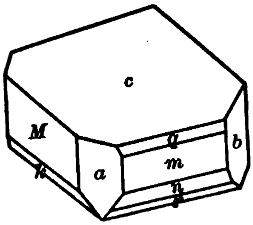
Figs. 361, 362 show two crystals of rhodonite, a species which is allied to pyroxene, and which approximates to it in angle and habit. Here the faces are: Pinacoids $a(100)$, $b(010)$, $c(001)$; prisms $m(110)$, $M(1\bar{1}0)$; pyramids $q(221)$, $k(\bar{2}21)$, $n(\bar{2}\bar{2}1)$, $r(\bar{1}\bar{1}1)$.

360

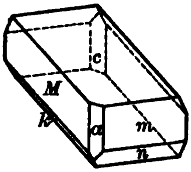


Axinite

361



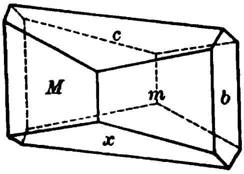
362



Rhodonite

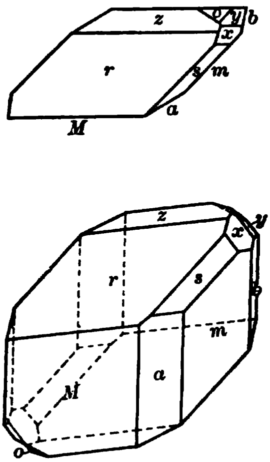
Further illustrations are given by Fig. 363 of albite and Fig. 364 of anorthite. The symbols of the faces, besides the pinacoids and the unit prisms, are as follows: Fig. 363, $x(\bar{1}01)$; Fig. 364, prisms $f(130)$, $z(1\bar{3}0)$; domes $t(207)$, $y(\bar{2}01)$, $e(021)$, $r(061)$, $n(0\bar{2}1)$; pyramids $m(111)$, $\alpha(1\bar{1}1)$, $o(\bar{1}\bar{1}1)$,

363



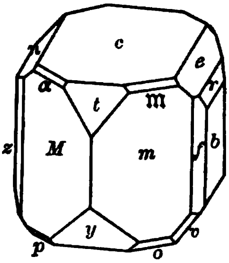
Albite

365



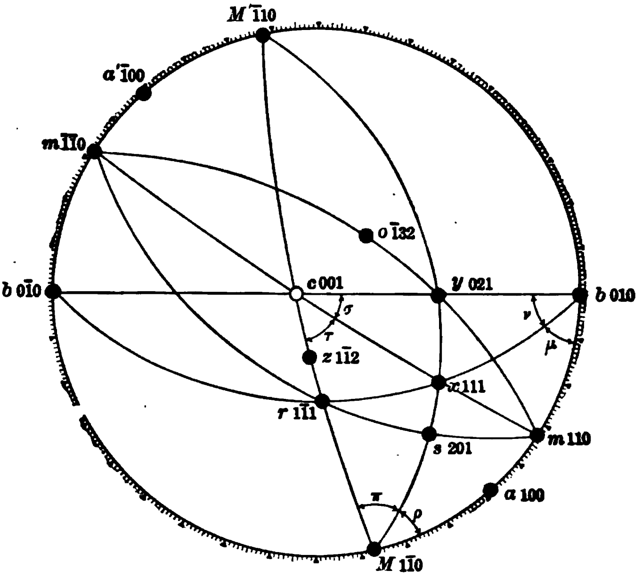
Axinite

364



Anorthite

366

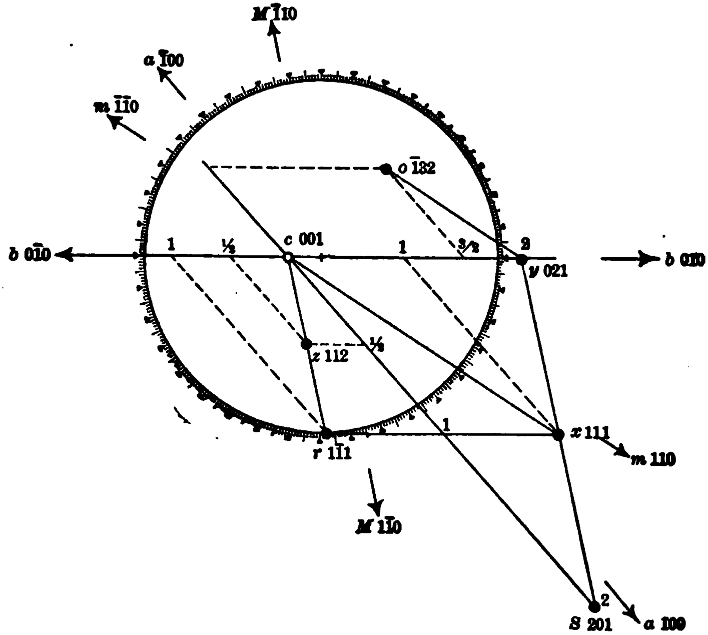


Stereographic Projection of an Axinite Crystal

$p(\bar{2}11)$. In Fig. 364 of anorthite the similarity of the crystal to one of orthoclase is evident on slight examination (cf. Figs. 340, 341), and careful study with the measurement of angles shows that the correspondence is very close. Hence in this case the choice of the fundamental planes is readily made.

Fig. 365 represents a crystal of axinite; Figs. 366 and 367 its stereographic and gnomonic projections.

367



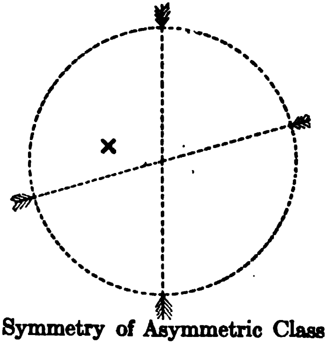
Gnomonic Projection of an Axinite Crystal

2. ASYMMETRIC CLASS (32). CALCIUM THIOSULPHATE TYPE

(*Hemihedral Class*)

220. Besides the normal class of the triclinic system there is another possible class, possessing symmetry neither with respect to a plane, axis nor center; in it a given form has *one face* only. This class finds examples among a number of artificial salts. One of these is calcium thiosulphate ($CaS_2O_3.6H_2O$); as yet no mineral species is known to be included here. This is the most general of all the thirty-two types of forms classified according to their symmetry and comes first, therefore, if the classes are arranged in order according to the degree of symmetry characterizing them. This class is one of those whose crystals may show circular polarization. This is true of eleven of the classes which have been described in the preceding pages.

368



Symmetry of Asymmetric Class

Mathematical Relations of the Triclinic System

221. Choice of Axes. — It is obvious, from what has been said as to the symmetry of this system, that *any* three faces of a triclinic crystal may be chosen as the pinacoids, or the faces which fix the position of the axial planes and the directions of the axes; moreover, there is a like liberty in the choice of the unit prisms, domes or pyramids which further fix the lengths of the axes.

When the crystal in hand is allied in form or composition to other species, whether of the same or different systems, this fact simplifies the problem and makes the choice of the fundamental forms easy. This is well illustrated, as already noted, by the triclinic feldspars (*e.g.*, albite and anorthite, Figs. 363, 364) which are near in angle to the allied monoclinic species orthoclase. Rhodonite (Figs. 361, 362), the triclinic member of the pyroxene group, is another good example.

In other cases, where no such relationship exists, and where varied habit makes different orientations plausible, there is but little to guide the choice. This is illustrated in the case of axinite (Fig. 360), where at least ten distinct positions have been assumed by different authors.

222. Axial and Angular Elements. — The *axial elements* of a triclinic crystal are: (1) the axial ratio, which expresses the lengths of the axes a and c in terms of the third axis, b; and (2) the angles between the axes α, β, γ (Fig. 357). There are here five quantities to be determined which obviously require the measurement of five independent angles between the faces.

The *angular elements* are usually taken as the angles between the pinacoids and, in addition, those between each pinacoid and the unit face lying in the zone of the other pinacoids; that is,

ab, $100 \wedge 010$, *ac*, $100 \wedge 001$, *bc*, $010 \wedge 001$;

also *am* $100 \wedge 110$, $001 \wedge 101$, $001 \wedge 011$;

or, instead, any one or all of these,

aM, $100 \wedge 1\bar{1}0$, $001 \wedge \bar{1}01$, $001 \wedge 0\bar{1}1$.

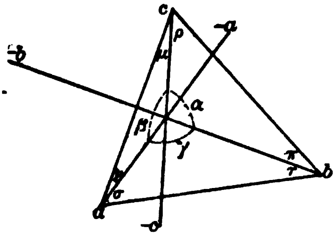
Of these six angles taken, one is determined when the others are known.

223. The mathematical relations existing between the axial angles and axial ratio, on the one hand, and the angles between the faces on the other, admit of being drawn out with great completeness, but they are necessarily complex and in general have little practical value. In fact, most of the problems likely to arise can be solved by means of the triangles of the spherical projection, together with the cotangent formula connecting four planes in the same zone (Art. **49**, p. 49); this will often be laborious and may require some ingenuity, but in general involves no serious difficulty. In connection with the use of the cotangent formula, it is to be noted that in certain commonly occurring cases its form is much simplified; some of these have already been explained under the monoclinic system (Art. **210**). The formulas given there are of course equally applicable here.

224. The first problem may be to find the axial elements from measured angles. Since these elements include five unknown quantities, viz., the three axial angles α, β, γ and the lengths of the axes a and c in terms of b, five measured angles are required, as already stated.

Fig. 369 represents the crystallographic axes of the triclinic mineral rhodonite. The positive ends of the three axes are joined by lines forming three triangles the angles of which are very important. In the triangle, for instance, which has the b and c axes for two of its sides since the length of the b axis is taken as 1·0, it is only necessary to know the angle α and either ρ or π in order to determine the length of the c axis. In the triangle that has the a and b axes for two of its sides it is necessary to know the value of γ and either σ or τ in order to determine the length of the a axis. And lastly in the triangle formed between the a and c axes, if the length of either of these axes is known, the length of the other can be determined from the angle β and either μ or ν. It is assumed that a

369



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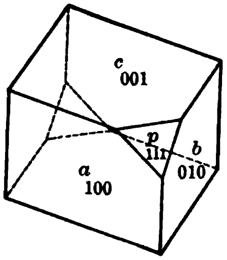
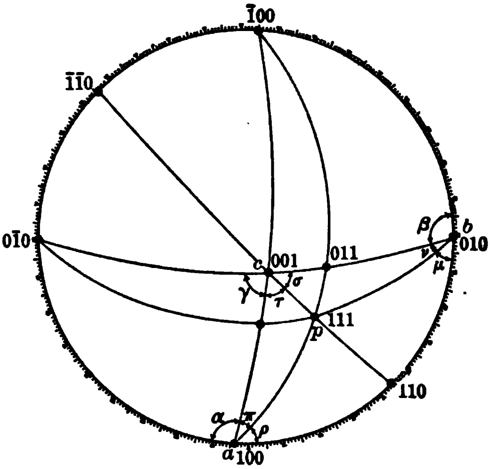


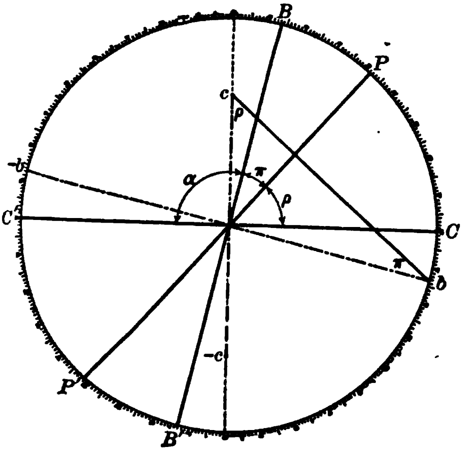
crystal of rhodonite showing the forms *a*(100), *b*(010), *c*(001) and *p*(111), see Fig. 370, has been measured and the poles of the faces plotted in the stereographic projection, Fig. 371. The angles between the great circles which connect these poles are the same as those shown in the triangles built upon the crystallographic axes, Fig. 369. With the angles between the different crystal faces known by measurement, it is easy, by the formulas of spherical trigonometry, to calculate the value of these other angles and from them obtain the axial ratio.

371



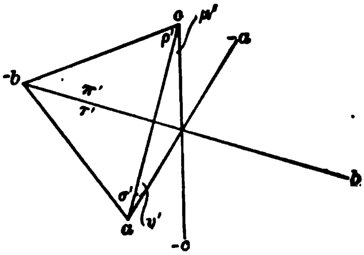
That the angles shown on the stereographic projection, Fig. 371, are identical with those in Fig. 369 may be proved as follows. Let Fig. 372 represent a vertical section cut through the spherical projection of rhodonite in such a way as to include the *b* and *c* crystallographic axes. The triangle, which has these axes as two sides and the three angles α, π and ρ, lies therefore in the plane of the figure. The normals to all faces parallel to the *c* axis, *i.e.* the prism zone, would lie in a plane at right angles to that axis. This plane would intersect the sphere of the spherical projection in a great circle which is represented on the stereographic projection, Fig. 371, by the divided circle. On Fig. 372 this great circle would appear in orthographic projection as the line C–C′ lying at right angles to the *c* axis. In the same way all faces lying parallel to the *b* axis, *i.e.* the zone (100)–(101)–(001), would have their normals in a plane which would be foreshortened to the line B–B′ in Fig. 372. Since the lines C–C′ and B–B′ are at right angles respectively to the *c* and *b* axes the angle between them must equal the axial angle, α. This same angle will appear therefore on the stereographic projection, Fig. 371, between the great circles of the two zones, the faces of which are parallel respectively to the *c* and *b* axes. Further the normals to all faces which intersect the *b* and *c* axes at their unit lengths would lie in a plane at right angles to the line *b*–*c*, Fig. 372. This plane would appear in orthographic projection as the line P–P′. On the stereographic projection, Fig. 371, this would be represented as the zonal circle passing through (100), (111), (011), ($\bar{1}00$). The angle between B–B′ and P–P′ will by construction equal π and that between C–C′ and P–P′ will equal ρ. These same angles will appear therefore in the stereographic projection between the corresponding zone circles. In the same way the identity of the angles γ, σ, τ, β, μ and ν in Figs. 369 and 371 can be proved.

372



With the necessary number of these angles given the formulas required for the calculation of the axial lengths are given below. The angles τ', σ', ν', μ', π' and ρ' are the corresponding angles to τ, σ, etc., in the adjacent quadrants, see Fig. 373.

373



$$\frac{\sin \tau}{\sin \sigma} = \frac{\sin \tau'}{\sin \sigma'} = \frac{a}{b}, \quad \frac{\sin \nu}{\sin \mu} = \frac{\sin \nu'}{\sin \mu'} = \frac{c}{a}, \quad \frac{\sin \pi}{\sin \rho} = \frac{\sin \pi'}{\sin \rho'} = \frac{c}{b}.$$

If the angles given are between the three pinacoids and the pyramid *hkl* (not the unit form) the relations are similar. That is, if for the face *hkl* the corresponding angles be represented by τ_0, σ_0, etc., where τ_0, σ_0 are the angles between the zone circles 100, 001 and 100, 010 respectively and the zone circle 001, *hk*0, these relations may be expressed in the general form

$$\frac{\sin \tau_0}{\sin \sigma_0} = \frac{\sin \tau_0'}{\sin \sigma_0'} = \frac{a}{\frac{h}{k}b} = \frac{k}{h} \cdot \frac{a}{b},$$

$$\frac{\sin \nu_0}{\sin \mu_0} = \frac{\sin \nu_0'}{\sin \mu_0'} = \frac{c}{\frac{l}{h}a} = \frac{h}{l} \cdot \frac{c}{a},$$

$$\frac{\sin \pi_0}{\sin \rho_0} = \frac{\sin \pi_0'}{\sin \rho_0'} = \frac{c}{\frac{l}{k}b} = \frac{k}{l} \cdot \frac{c}{b}$$

Thus for the face 321 the formulas become

$$\frac{\sin \tau_0}{\sin \sigma_0} = \frac{a}{\frac{3}{2}b} = \frac{2\,a}{3\,b}, \quad \frac{\sin \nu_0}{\sin \mu_0} = \frac{3c}{a}, \quad \frac{\sin \pi_0}{\sin \rho_0} = \frac{2c}{b}.$$

It is also to be noted that

$$\alpha = 180° - A, \qquad \beta = 180° - B, \qquad \gamma = 180° - C,$$

where A, B, C are the angles in the pinacoidal spherical triangle 100·010·001 at these poles respectively. That is,

$$\begin{aligned} A &= \pi + \rho = \pi_0 + \rho_0 = (180° - \alpha); \\ B &= \nu + \mu = \nu_0 + \mu_0 = (180° - \beta); \\ C &= \tau + \sigma = \tau_0 + \sigma_0 = (180° - \gamma). \end{aligned}$$

Also

$$180° - A = \pi' + \rho' = \pi_0' + \rho_0' = \alpha.$$

Hence, having given, by measurement or calculation, the angles between the faces $ab(100 \wedge 010)$, $ac(100 \wedge 001)$ and $bc(010 \wedge 001)$, which are the sides of this triangle, the angles A, B, C are calculated and their supplements are the axial angles α, β, γ respectively.

Still another series of equations are those below, which give the relations of the angles μ, ν, ρ, etc., to the axes and axial angles. By means of them, with the sine formulas given above, the angular elements (and other angles) can be calculated from the axial elements.

$$\tan \mu = \frac{a \sin \beta}{c + a \cos \beta}; \quad \tan \nu = \frac{c \sin \beta}{a + c \cos \beta}.$$

$$\tan \rho = \frac{b \sin \alpha}{c + b \cos \alpha}; \quad \tan \pi = \frac{c \sin \alpha}{b + c \cos \alpha}.$$

$$\tan \tau = \frac{a \sin \gamma}{b + a \cos \gamma}; \quad \tan \sigma = \frac{b \sin \gamma}{a + b \cos \gamma}.$$

These equations apply when $\mu + \nu$, etc., is less than 90°; if their sum is greater than 90° the sign in the denominator is negative.

207. The following equations are also often useful.

$$\tan \alpha = \frac{2 \sin \rho \sin \rho'}{\sin (\rho - \rho')} = \frac{2 \sin \pi \sin \pi'}{\sin (\pi - \pi')}.$$

$$\tan \beta = \frac{2 \sin \mu \sin \mu'}{\sin (\mu - \mu')} = \frac{2 \sin \nu \sin \nu'}{\sin (\nu - \nu')}.$$

$$\tan \gamma = \frac{2 \sin \tau \sin \tau'}{\sin (\tau - \tau')} = \frac{2 \sin \sigma \sin \sigma'}{\sin (\sigma - \sigma')}.$$

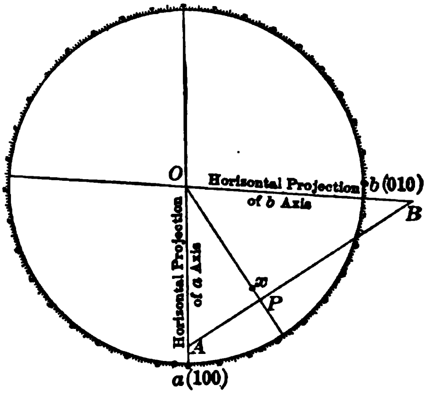
Also,

$$\alpha + \pi + \rho = \beta + \mu + \nu = \gamma + \tau + \sigma = 180°.$$

The calculation, from the angular elements or from the assumed fundamental measured angles, either (1) of the angular position of any face whose symbol is given, or (2) of the symbol of an unknown face for which measured angles are at hand, requires no further explanation. The cotangent formula is all that is needed in a single zone, and the solution of spherical triangles on the projection (with the use of the sine formulas) will suffice in addition in all ordinary cases.

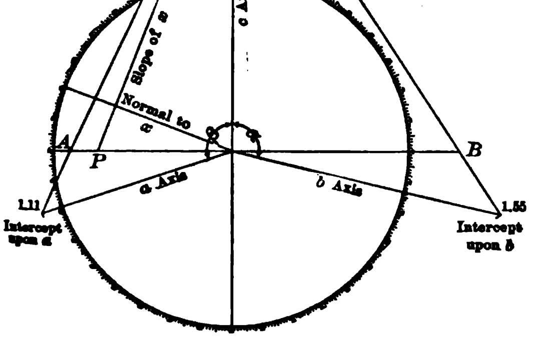
225. To determine, by plotting, the axial elements of a triclinic crystal, having given the stereographic projection of its forms. In order to solve this problem it is necessary to have given the position of the poles of the unit forms (100), (010), (001), (111) or to be able to locate them by means of their zonal relations. Through these poles the various zonal circles are drawn as shown in the case of rhodonite, Fig. 371. The angles α, β, γ, π, ρ, etc., are then given upon the projection. These angles can be measured as described in Art. **41,** p. 39. Taking next a certain line as representing the unit length of the b axis and knowing the angles α, π and ρ the triangle that includes the b and c axes, see Fig. 369, can be drawn to scale and the unit length of the c axis determined. In a similar way the length of the a axis can be found.

374


O
Horizontal Projection of b Axis
b (010)
B
Horizontal Projection of a Axis
x
P
A
a (100)

226. To determine, by plotting, the indices of a face upon a triclinic crystal, having given the position of its pole in the stereographic projection and the axial elements of the mineral. To illustrate this problem a possible pyramid face on rhodonite will be used. Its pole is located in the stereographic projection at x, Fig. 374. The position of the poles of the faces $a(100)$ and $b(010)$ must also be known. The directions of the intersections of the planes of the a–c and b–c axes with the plane of the projection can then be drawn. These lines will represent the horizontal projections of the a and b crystallographic axes. A radial line is then drawn from the center of the projection, O, through x. Another line, A–P–B, is drawn perpendicular to this line at any convenient distance from the center, O. The line A–P–B will represent the direction of intersection of the face x with the horizontal plane of the projection. The intercept that the face will make upon the vertical axis can be found by the construction of a right triangle with O–P as its base, a line representing the c axis as its vertical side and the angle between O–x as the angle between the base and the hypothenuse, see Fig. 375. Under the assumed conditions the face will intersect the c axis at a distance of 1·93, the radius of the circle in the figure being 1·0. The face will also pass through the points A and B on the horizontal projections of the a and b axes. With the known angles β and α it is possible to construct the a and b axes with their proper angular relations to the c axis. The intercepts of the face upon these two axes will be given by the extension of the lines from the point 1·93 on the c axis to the points A and B. In this way the intercepts of the face upon the three axes were obtained as 1·11a, 1·55b,

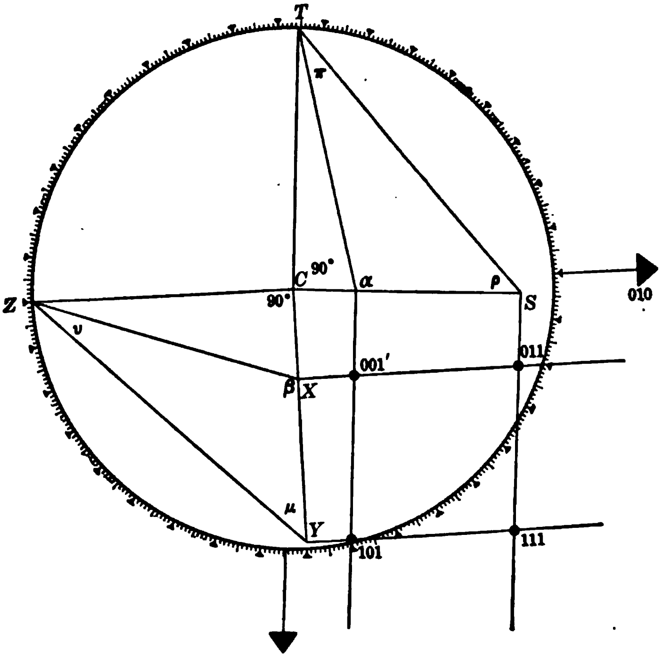
375



1·93*c*. By dividing these numbers by 1·55 we get the intercepts expressed in terms of the length of the *b* axis, considering that as 1·0. The intercepts then become 0·71*a*, 1*b*, 1·24*c*. When these are compared with the axial ratio of rhodonite, $a : b : c = 1{\cdot}114 : 1 : 0{\cdot}986$, the parameters of the face are found to be ⅔*a*, 1*b*, 2*c*. The indices of *x* are therefore 321.

227. To determine, by plotting, the axial elements of a triclinic crystal having given the gnomonic projection of its forms. To illustrate this problem it is assumed that the positions of the poles of the faces, (100), (010), (001), (101), (011) and (111) on rhodonite are known, see Fig. 376. If this figure is compared with the stereographic projection of the same forms given in Fig. 371, it will be seen that the angle between the zones (100)–(101)–(001) and (100)–(111)–(011) is equal to π, that between the zones (100)–(111)–(011) and (100)–(110)–(010) is equal to ρ, between (010)–(011)–(001) and (010)–(111)–(101) is equal to ν and between (010)–(111)–(101) and (010)–(110)–(100) is equal to μ. The method by which the angles between these various zones may be measured was explained in Art. 42, p. 43, and is illustrated by the construction of Fig. 376. From these angles triangles can be readily constructed to give the lengths of the *a* and *c* axes in terms of the *b* axis, with its length taken as equal to 1·0.

376



228. To determine, by plotting, the indices of the forms of a triclinic crystal, having given the position of other poles upon the gnomonic projection. The method for the solution of this problem is similar to that already described under the previous systems. The difference lies in the fact that the lines of reference upon which are plotted the intercepts of the lines drawn to them from the poles of the faces make oblique angles with each other. These reference lines are taken as the zonal lines (001)–(101) and (001)–(011) and the intercepts from which the indices are determined are measured from the pole of (001). A study of the gnomonic projection of axinite, Fig. 367, will illustrate this problem.

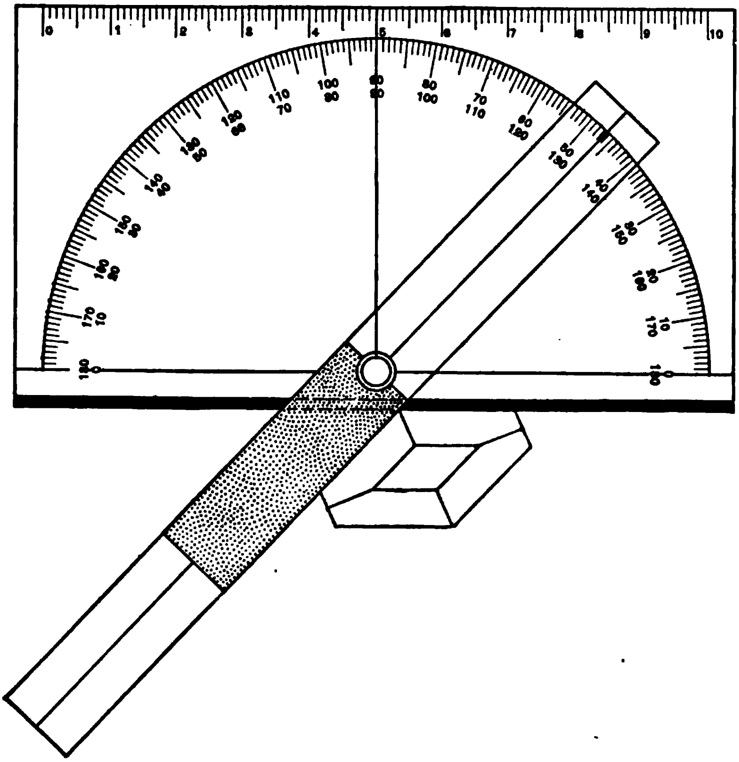
MEASUREMENT OF THE ANGLES OF CRYSTALS

229. Contact-Goniometers. — The interfacial angles of crystals are measured by means of instruments which are called *goniometers*.

The simplest form is the contact- or hand-goniometer one form of which is represented in Fig. 377.

This contact-goniometer consists of a card on which is printed a semicircular arc graduated to half degrees at the center of which is fastened a celluloid arm which may be turned to any desired position. The method of use of the goniometer is illustrated in Fig. 377. The bottom of the card and the blackened end of the celluloid arm are brought in as accurate contact as possible with the two crystal faces, the angle between which is desired. Care must be taken to see that the plane of the goniometer is at right angles to the edge of intersection between the two faces. Another model of the contact-goniometer, Fig. 378, has two arms swiveled together and separate from the graduated arc. The crystal angle is obtained by means of the arms and then the angle between them measured by placing them upon the graduated arc. This latter type is employed in cases where the crystal lies in such a position as to prevent the use of the former.*

377



Penfield Contact Goniometer, Model B

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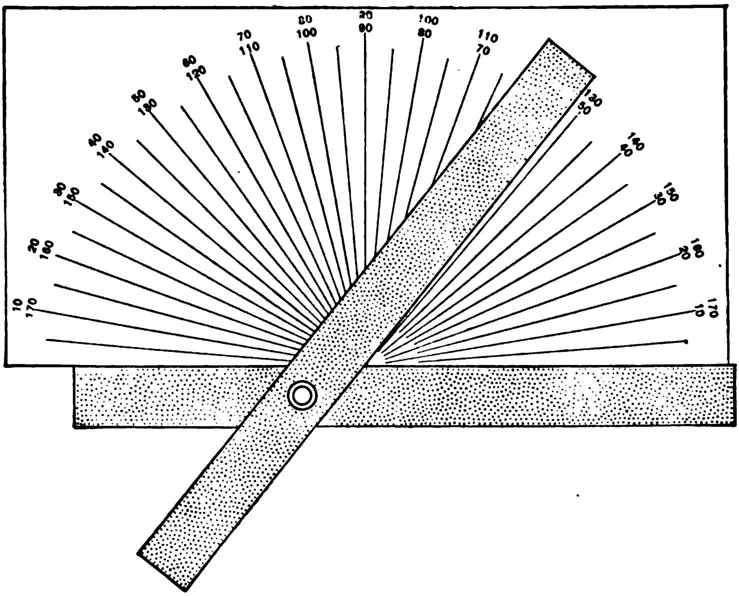
* These simple types of contact-goniometers were devised by S L. Penfield and can be obtained by addressing the Mineralogical Laboratory of the Sheffield Scientific School of Yale University, New Haven, Ct.

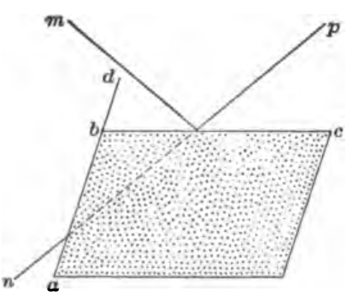
The contact-goniometer is useful in the case of large crystals and those whose faces are not well polished; the measurements with it, however, are seldom accurate within a quarter of a degree. In the finest specimens of crystals, where the faces are smooth and lustrous, results far more accurate may be obtained by means of a different instrument, called the reflecting goniometer.

378



Penfield Contact Goniometer, Model A

379

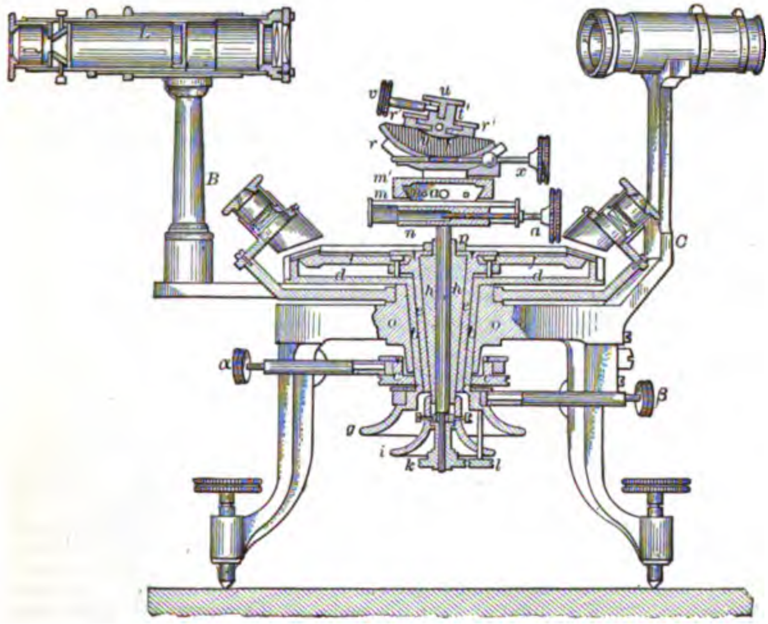


230. Reflecting Goniometer. — This type of instrument was devised by Wollaston in 1809. It has undergone extensive modifications and improvements since that time. Only the perfected forms that are in common use to-day will be described.

The principle underlying the construction of the reflecting goniometer will be understood by reference to the figure (Fig. 379), which represents a section of a crystal, whose angle, *abc*, between the faces *ab*, *bc*, is required. Let the eye be placed at *P* and the point *M* be a source of light. The eye at *P*, looking at the face of the crystal, *bc*, will observe a reflected image of *m*, in the direction of *Pn*. The crystal may now be so changed in its position that the same image is seen reflected by the next face and in the same direction, *Pn*. To effect this, the crystal must be turned around, until *abd* has the present direction of *bc*. The angle *dbc* measures, therefore, the number of degrees through which the crystal must be turned; it may be measured by attaching the crystal to a graduated circle, which turns with the crystal. This angle is the supplement of the interior angle between the two faces, or in other words is the *normal angle*, or angle between the two poles (see Art. 43, p. 44). The reflecting goniometer hence gives directly the angle needed on the system of Miller here followed.

231. Horizontal Goniometer. — A form of reflecting goniometer well adapted for accurate measurements is shown in Fig. 380. The particular form of instrument here figured * is made by Fuess.

380



One-circle Reflection Goniometer

The instrument stands on a tripod with leveling screws. The central axis, *o*, has within it a hollow axis, *b*, with which the plate, *d*, turns, carrying the verniers and also the observing telescope, the upright support of which is shown at *B*. Within *b* is a second hollow axis, *e*, which carries the graduated circle, *f*, above, and which is turned by the screw-head, *g*; the tangent screw, *α*, serves as a fine adjustment for the observing telescope, *B*, the screw, *c*, being for this purpose raised so as to bind *b* and *e* together. The tangent screw, *β*, is a fine adjustment for the graduated circle. Again, within *e* is the third axis, *h*, turned by the screw-head, *i*, and within *h* is the central rod, which carries the support for the crystal, with the adjusting and centering contrivances mentioned below. This rod can be raised or lowered by the screw, *k*, so as to bring the crystal to the proper height — that is, up to the axis of the telescope; when this has been accomplished, the clamp at *p*, turned by a set-key, binds *s* to the axis, *h*. The movement of *h* can take place independently of *g*, but after the crystal is ready for measurement these two axes are bound together by the set-screw, *l*. The signal telescope is supported at *C*, firmly attached to one of the legs of the tripod. The crystal is mounted on the plate, *u*, with wax, the plate is clamped by the screw, *v*. The *centering* apparatus consists of two slides at right angles to each other (one of these is shown in the figure) and the screw, *a*, which works it; the end of the other corresponding screw is seen at *a'*. The *adjusting* arrangement consists of two cylindrical sections, one of them, *r*, shown in the figure, the other at *r'*; the cylinders have a common center. The circle on *f* is graduated to degrees and quarter degrees, and the vernier gives the readings to 30″.

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* The figure here used is from the catalogue of Fuess.

A brilliant source of light is placed behind the collimator tube which is at the top of the support *C*. Openings of various size and character are provided at the rear end of this tube in order to modify the size and shape of the beam of light that is to be reflected from the crystal faces. The most commonly used opening is one made by placing two circular disks nearly in contact with each other leaving between them an hour-glass shaped figure. The telescope tube *L* is provided with several removable telescopes with lenses which have different angular breadths and magnifying powers and hence are suitable for observing faces varying in size and degree of polish. At the front of the tube *L* there is a lens which is so pivoted that it may be thrown into or out of the axis of the telescope. When this lens lies in the axis of the tube it converts the telescope into a low-power microscope with which the crystal may be observed. Without this lens the telescope has a long-distance focus and only the beam of light reflected from the crystal face can be seen.

The method of use of the instrument is briefly as follows. The little plate *u* is removed and upon it is fastened by means of some wax the crystal to be measured. The faces of the zone that is to be measured should be placed as nearly as possible vertical to the surface of this plate. It will usually facilitate the subsequent adjustment if a prominent face in this zone be placed so that it is parallel to one of the edges of the plate *u*. This plate with the attached crystal is then fastened in place by the screw *v*. During the preliminary adjustments of the crystal the small lens in front of the tube *L* is placed in its axis and the crystal observed through the microscope thus formed. It is usually better also to make these first adjustments outside the dark room in daylight. By means of the screw-head *k* the central post is raised or lowered until the center of the crystal lies in the plane of the telescope. Next by means of the two sliding tables controlled by the screw-heads *a* and *a'* the crystal is adjusted so that the edge over which the angle is to be measured coincides with the axis of the instrument. This adjustment is most easily accomplished by turning the central post of the instrument until one of these sliding plates lies at right angles to the telescope and then by turning its screw-head bring the intersection in question to coincide with the vertical cross-hair of the telescope tube. Then turn the post until the other plate lies at right angles to the telescope and make a similar adjustment. Then in a similar manner by means of the tipping screws *x* and *y* bring the intersection between the faces to a position parallel with the vertical cross-hair of the telescope. By a combination of these adjustments this edge should be made to coincide with the vertical cross-hair and to remain stationary while the crystal is revolved upon the central post of the instrument. Next the instrument is taken into the dark room and a light placed behind the collimator tube, and the crystal turned until one of the faces is seen through the tube *L* to be brightly illuminated. Then the little lens in the front of this tube is raised and the reflection of the beam of light, or *signal* as it is called, should lie in the field. If the preliminary adjustments were accurate the horizontal cross-hair will bisect this signal. In the majority of cases, however, further slight adjustments will be necessary. Before the angles between the faces can be measured their various signals must all be bisected by the horizontal cross-hair. When these conditions are fulfilled each signal in turn is brought into place so that it is bisected also by the vertical cross-hair and its angular position read by means of the graduated scale and vernier. The difference between the angles for two faces gives the normal angle between them. In making these readings care must be taken that the plate on which the graduated circle is engraved is turned with the central post. In order to do this only the screw-head g must be used unless, as is wise, the two screw-heads i and g have been previously clamped together by means of l. For the accurate adjustment of the signals on the vertical cross-hair the tangent screw β is used. In making a record of the angles measured it is important to note accurately the face from which each signal is derived and the character of the signal. It is frequently helpful to make a sketch of the outlines of the different faces and number or letter them.

232. Theodolite-Goniometer. — A form of goniometer * having many practical advantages and at present in wide use has two independent circles and is commonly known as the *two-circle goniometer*. It is used in a manner analagous to that of the ordinary theodolite. Instruments of this type were devised independently by Fedorow, Czapski and Goldschmidt. Other models have been described since. In addition to the usual graduated horizontal circle of Fig. 380, and the accompanying telescope and collimator, a second graduated circle is added which revolves in a plane at right angles to the first. Fig. 381, after Goldschmidt, gives a cross-sectional view of one of

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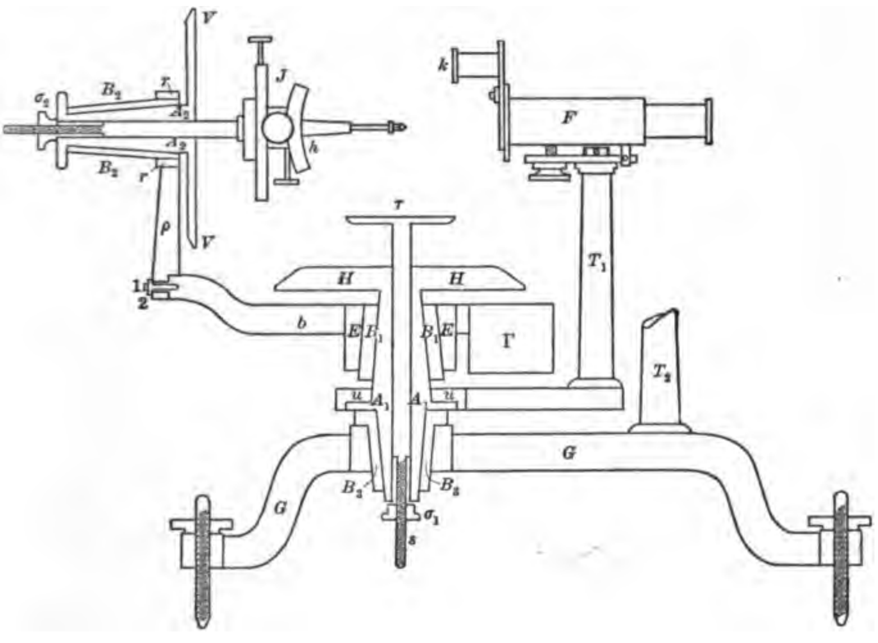

Two-circle Reflection Goniometer

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* Fedorow, Universal or Theodolit-Goniometer, Zs. Kryst., **21**, 574, 1893; **22**, 229, 1893; Czapski, Zeitschr. f. Instrumentenkunde, 1, 1893; Goldschmidt, Zs. Kryst., **21**, 210, 1892; **24**, 610, 1895; **25**, 321, 538, 1896; **29**, 333, 589, 1898. On the method of Goldschmidt, see Palache, Am. J. Sc., **2**, 279, 1896; Amer. Mineral, **5**, No. 2, *et seq.*, 1920. A simplified form of the theodolite-goniometer is described by Stöber, Zs. Kryst., **29**, 25, 1897; **54**, 442.

the earlier machines devised by him. It will serve to illustrate the essential features of the instrument.

The crystal to be measured is attached at the end of the axis (*h*) of the vertical circle and so adjusted by means of suitable centering and tipping devices that a given plane, called the polar plane, is normal to this axis and lies directly over the axis of the horizontal circle. In using the instrument, instead of directly measuring the interfacial angles of the crystal, the position of each face is determined independently of the others by the measurement of its angular co-ordinates, or what might be called its latitude and longitude. These co-ordinates are the angles (ϕ and ρ of Goldschmidt) measured, respectively, in the vertical and horizontal circles from an assumed pole and meridian, which are fixed, in most cases, by the symmetry of the crystal. In practice the crystal is usually so mounted that its prismatic zone is perpendicular to the vertical circle. A plane at right angles to this zone, *i.e.*, the basal plane in the first four systems, is known as the polar plane and its position when reflecting the signal into the telescope establishes the zero position for the horizontal circle. The position of a pinacoid, usually the 010 plane, in the prism zone establishes the zero position for the vertical circle. For example, with an orthorhombic crystal, for the pyramid 111, the angle ϕ (measured on the vertical circle) is equal to 010 ∧ 110 and ρ (measured on the horizontal circle) is equal to 001 ∧ 111.

Goldschmidt has shown that this instrument is directly applicable to the system of indices and methods of calculation and projection adopted by him, which admit of the deducing of the elements and symbols of a given crystal with a minimum of labor and calculation.* Fedorow has also shown that this instrument, with the addition of the appliances devised by him, can be most conveniently used in the crystallographic and optical study of crystals.

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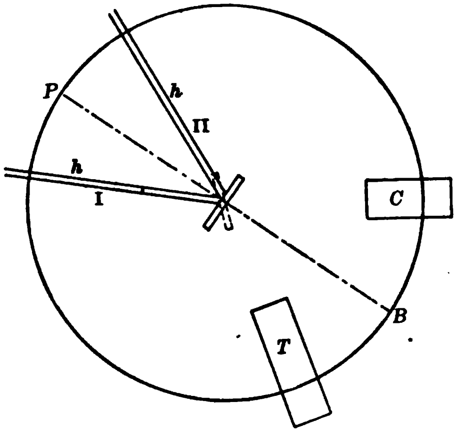

The following hints as to the methods of using this instrument may prove helpful. The telescope and collimator tube are placed at some convenient angle to each other (usually about 70°) and then clamped in position. The next step is to find the polar position of the horizontal circle, *i.e.*, the position at which a crystal plane lying at right angles to the axis of the vertical circle will throw the reflected beam of light on to the cross-hairs of the telescope. Obviously the plane under these conditions must be normal to the bisector of the angle between the axes of the collimator and telescope, the line B–P, Fig. 382. The method by which this polar position is found is as follows: Some reflecting surface is mounted upon the end of the post *h*, Figs. 381, 382, making some small inclined angle to the plane normal to that post. Then by turning the instrument in both the horizontal and vertical planes this surface is brought into the proper position to reflect the signal into the telescope, see position I, Fig. 382. The horizontal angle of this position is noted. Then the vertical circle is turned through an angle of 180°. This brings the reflecting surface into the position indicated by the dotted lines in the figure. In order to again bring this surface back to its reflecting position the vertical circle with the post *h* must be moved in the horizontal plane until the position II is reached. The horizontal reading of this position is also noted. The angle midway between these two readings is the polar position desired. That is, when the post *h* lies in the direction of the broken line P–B a plane normal to its axis would reflect a beam of light from the collimator into the telescope. This position constitutes the zero position of the horizontal circle from which the ρ angles are measured.

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* See Goldschmidt's Krystallographische Winkeltabellen (432 pp., Berlin, 1897). This gives the angles required by his system for all known species. See also Zs. Kryst., **29**, 361, 1898. The same author's atlas der Krystallformen, 1913 *et seq.*, is a monumental work giving all previously published crystal figures together with a discussion of the forms observed upon them.

The method used to adjust a crystal upon the instrument so that it will occupy the proper position for measurement will vary with the character of the crystal. A few illustrations follow. 1. *If the crystal has a basal plane at right angles to a prism zone.* The crystal is mounted upon the post *h* so that the faces of the prism zone lie as nearly as possible parallel to the axis of the post or the basal plane as nearly as possible normal to it. Then the instrument is moved until the reading of the horizontal circle agrees with the polar position already determined. Then by means of the tipping screws the crystal is moved until the reflection from the basal plane is centered upon the cross-hairs of the telescope. If the adjustments have been accurately made the signal will remain stationary while the vertical circle is revolved. Next the horizontal circle is moved through an angle of 90°. This will bring the reflections from the faces of the prism zone into the telescope. If the pinacoid 010 is present the vertical circle is turned until the reflected signal from this face falls on the horizontal cross-hair. The reading of the vertical circle under these conditions establishes the position of the meridian from which the ϕ angles are measured. If the pinacoid 010 is not present it is usually possible to determine its theoretical position from the position of other faces in the prism zone or in the zone between 010 and 100. 2. *If there is no basal plane present upon the crystal but a good prism zone.* Under these circumstances the horizontal circle is turned until it is exactly 90° away from its determined polar angle and then the crystal adjusted by means of the tipping screws until the signals from the faces of the prism zone all fall on the vertical cross-hair as the vertical circle of the goniometer is turned. 3. *If neither basal plane or prism zone is available but there are two or more faces present which are equally inclined to a theoretical basal plane.* First adjust the crystal as nearly as possible in the proper position and then obtaining reflections from these faces note the horizontal circle reading in each case. Take an average of these readings and adding or subtracting this angle from the polar angle of the horizontal scale place the instrument in this position. Then by tipping the crystal try to bring it into such a position that all of these faces will successively reflect the signal into the telescope as the vertical circle is turned. The operation may have to be repeated two or three times before the final adjustment is made. If the angle between the inclined faces and the theoretical base is known the instrument can be set in the proper position at once and the crystal brought into adjustment very quickly. Other problems will arise in practice but their solution will be along similar lines to those suggested above. It may frequently happen that more than one method of adjustment may be used with a given crystal. In that case the faces giving the best reflections should be used. It should be emphasized that the preliminary adjustment of the crystal is of supreme importance since all measurements of the co-ordinates of the different faces depend upon it. It is wise to check the adjustment in all possible ways before making the measurements.

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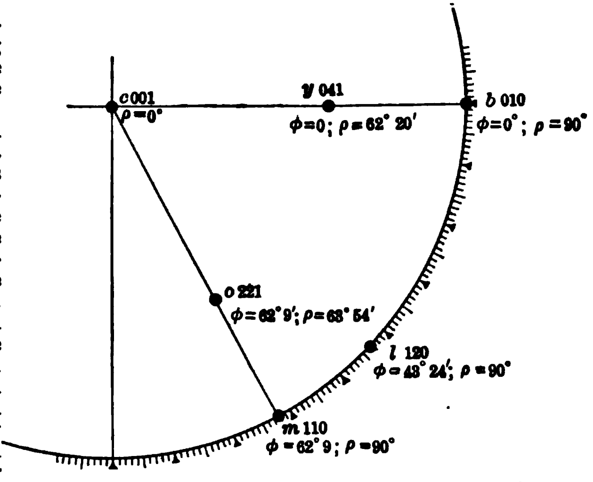
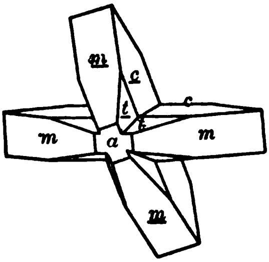


After these adjustments have been completed the crystal is turned about both the horizontal and vertical planes so that each face upon it successively reflects the signal into the telescope. The horizontal and vertical readings are made in each case. The forms present can then be readily plotted in either the stereographic or gnomonic projections. Fig. 383 shows how the forms of a simple crystal of topaz could be plotted in the stereographic projection from the ϕ and ρ angles obtained from it — the two circle goniometer measurements. For each face the vertical circle angle, ϕ, is plotted on the divided circle, the position of $b(010)$ giving the zero point while the horizontal circle angle is plotted on a radial line from the center of the projection, the position of $c(001)$ giving its zero point.

COMPOUND OR TWIN CRYSTALS

233. Twin Crystals. — Twin crystals are those in which one or more parts regularly arranged are in reverse position with reference to the other part or parts. They often appear externally to consist of two or more crystals symmetrically united, and sometimes have the form of a cross or star. They also exhibit the composition in the reversed arrangement of part of the faces, in the striæ of the surface, and in re-entering angles; in certain cases the compound structure can only be surely detected by an examination in polarized light. The above figures (Figs. 384–386) are examples of typical kinds of twin crystals, and many others are given on the pages following.

384



Thenardite

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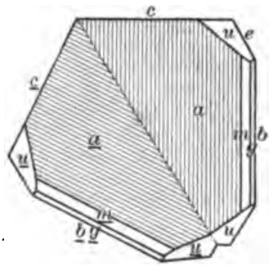

Columbite

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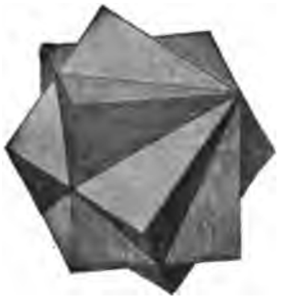


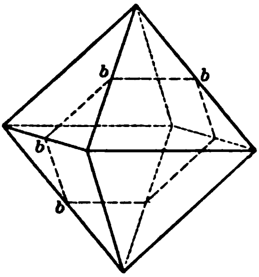
Fluorite

To illustrate the relation of the parts in a twin crystal, Figs. 387, 388 are given. Fig. 387 shows a regular octahedron divided into halves by a plane parallel to an octahedral face. If now the lower half be supposed to be revolved 180° about an axis normal to this plane, the twinned octahedron of Fig. 388 results. This is a common type of twin in the isometric system, and the method here employed to describe the position of the parts of the crystal to one another is applicable to nearly all twins.

234. Distinction between Twinning and Parallel Grouping. — It is important to understand that crystals, or parts of crystals, so grouped as to occupy parallel positions with reference to each other — that is, those whose similar faces are parallel — are not called twins; the term is applied only where the crystals or parts of them are united in their reversed position in accordance with some deducible mathematical law. Thus Fig. 389, which represents a cluster of partial crystals of analcite, is a case of *parallel grouping* simply (see Art. 252); but Fig. 407 illustrates twinning, and this is true of Fig. 416 also. Since though in these cases the axes remain parallel the similar faces (and planes of symmetry) are reversed in position.

235. Twinning-Axis. — The relative position of the parts of a twinned crystal can be best described as just explained, by reference to that line or axis called the *twinning-axis*, a revolution of 180° about which would serve to bring the twinned part parallel to the other, or in other words, which would cause one of the parallel parts to take a twinned position relatively to the other.

387



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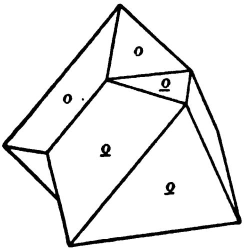
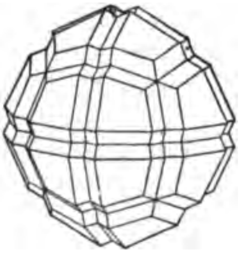


Twinned Octahedron

389



Analcite

The twinning-axis is always a possible crystalline line — that is, either a crystallographic axis or the normal to some possible face on the crystal, usually one of the common fundamental forms.

It is not to be supposed that ordinary twins have actually been formed by such a revolution of the parts of crystals, for all twins (except those of secondary origin, see Art **242**) are the result of regular molecular growth or enlargement, like that of the simple crystal. This reference to a *revolution*, and an *axis of revolution*, is only a convenient means of describing the forms.

In certain rare cases, particularly of certain pseudo-hexagonal species, a revolution of 60° or 120° about a normal to the base has been assumed to explain the complex group observed.

236. Twinning-Plane. — The plane normal to the axis of revolution is called the *twinning-plane*. The axis and plane of twinning bear the same relation to both individuals in their reversed position; consequently, in the majority of cases, the twinned crystals are symmetrical with reference to the twinning-plane.

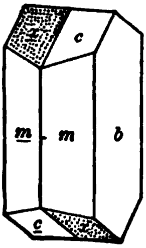
The twinning-plane is, with rate exceptions, parallel to a possible occurring face on the given species, and usually one of the more frequent or fundamental forms. The exceptions occur only in the triclinic and monoclinic systems, where the twinning-axis is sometimes one of the oblique crystallographic axes, and then the plane of twinning normal to it is obviously not necessarily a crystallographic plane; this is conspicuously true in albite.

237. Composition-Plane. — The plane by which the reversed crystals are united is the *composition-plane*. This and the twinning-plane very commonly coincide; this is true of the simple example given above (Fig. 388), where the plane about which the revolution may be conceived to take place (normal to the twinning-axis) and the plane by which the semi-individuals are united are identical. When not coinciding, the two planes are generally at right angles to each other — that is, the composition-plane is parallel to the axis of revolution. Examples of this are given below. Still again, where the crystals are not regularly developed, and where they interpenetrate, the contact surface may be interrupted, or may be exceedingly irregular. In such cases the axis and plane of twinning have, as always, a definite position, but the composition-plane loses its significance.

Thus in quartz twins the interpenetrating parts have often no rectilinear boundary, but mingle in the most irregular manner throughout the mass, showing this composite irregularity by abrupt variations in the character of the surfaces. This irregular internal structure, found in many quartz crystals, even the common kinds, is well brought out by means of polarized light; also by etching with hydrofluoric acid.

The composition-plane has sometimes a more definite signification than the twinning-plane. This is due to the fact that in many cases, whereas the former is fixed, the twinning-axis (and twinning-plane) may be exchanged for another line (and plane) at right angles to each, respectively, since a revolution about the second axis will also satisfy the conditions of producing the required form. An example of this is furnished by Fig. 390, of orthoclase; the composition-plane is here fixed — namely, parallel to the crystal face, *b*(010). But the axis of revolution may be either (1) parallel to this face and normal to *a*(100), which is then consequently the twinning-plane, though the axis does not coincide with the crystallographic axis; or (2) the twinning-axis may be taken as coinciding with the vertical axis, and then the twinning-plane normal to it is not a crystallographic face. In other simpler cases, also, the same principle holds good, generally in consequence of the possible mutual interchange of the planes of twinning and composition. In most cases the true twinning-plane is evident, since it is parallel to some face on the crystal of simple mathematical ratio.

390



Orthoclase

238. An interesting example of the possible choice between two twinning-axes at right angles to each other is furnished by the species staurolite. Fig. 439 shows a prismatic twin from Fannin Co., Ga. The measured angle for *bb* was 70° 30′. The twinning-axis deduced from this may be normal to the face (230), which would then be the twinning-plane. Or, instead of this axis, its complementary axis at right angles to it may be taken, which would equally well produce the observed form. Now in this species it happens that the faces, $\bar{1}30$ and 230 (over 100), are almost exactly at right angles with each other, and, according to the latter supposition, 130 becomes the twinning-plane, and the axis of revolution is normal to it. Hence, either 230 or 130 may be the twinning-plane, either supposition agreeing closely with the measured angle (which could not be obtained with great accuracy). The former method of twinning (tw. pl. 230) conforms to the other twins observed on the species, and hence it may be accepted. What is true in this case, however, is not always true, for it will seldom happen that of the two complementary axes each is so nearly normal to a face of the crystal. In most cases one of the two axes conforms to the law in being a normal to a possible face, and the other does not, and hence there is no doubt as to which is the true twinning-axis.

Another interesting case is that furnished by columbite. The common twins of the species are similar to Fig. 385, p. 160, and have *e*(021) as the twinning-plane; but twins also occur like Fig. 434, p. 169, where the twinning-plane is *q*(023). The two faces, 021 and $0\bar{2}3$, are nearly at right angles to each other, but the measured angles are in this case sufficiently exact to prove that the two kinds cannot be referred to one and the same law.

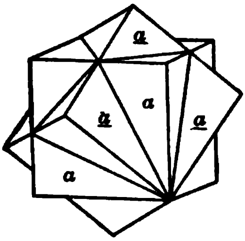
239. Contact- and Penetration-Twins. — In *contact-twins*, when normally formed, the two halves are simple connate, being united to each other by the composition-plane; they are illustrated by Figs. 385, 388, etc. In actual crystals the two parts are seldom symmetrical, as demanded by theory, but one may preponderate to a greater or less extent over the other;

in some cases only a small portion of the second individual in the reversed position may exist. Very great irregularities are observed in nature in this respect. Moreover, the re-entering angles are often obliterated by the abnormal developments of one or other of the parts, and often only an indistinct line on some of the faces marks the division between the two individuals.

Penetration-twins are those in which two or more complete crystals interpenetrate, as it were crossing through each other. Normally, the crystals have a common center, which is the center of the axial system for both; practically, however, as in contact-twins, great irregularities occur.

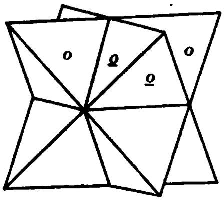
Examples of twins of this second kind are given in the annexed figures, Figs. 386 and 391 of fluorite, Fig. 392 of tetrahedrite, and Fig. 393 of chabazite. Other examples occur in the pages following, as, for instance, of the species staurolite (Figs. 438–441), the crystals of which sometimes occur in nature with almost the perfect symmetry demanded by theory. It is obvious that the distinction between contact- and penetration-twins is not of great importance, and the line cannot always be clearly drawn between them.

391



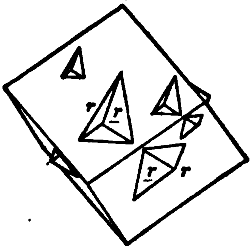
Fluorite

392



Tetrahedrite

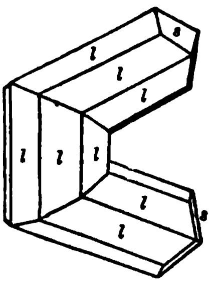
393



Chabazite

240. Paragenic and Metagenic Twins. — The distinction of paragenic and metagenic twins belongs rather to crystallogeny than crystallography. Yet the forms are often so obviously distinct that a brief notice of the distinction is important.

394



Rutile

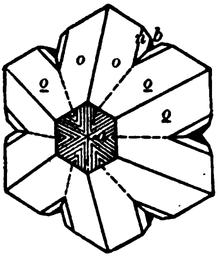
In ordinary twins, the compound structure had its beginning in a nucleal compound molecule, or was compound in its very origin; and whatever inequalities in the result, these are only irregularities in the development from such a nucleus. But in others, the crystal was at first simple; and afterwards, through some change in itself or in the condition of the material supplied for its increase, received new layers, or a continuation, in a reversed position. This mode of twinning is *metagenic*, or a result subsequent to the origin of the crystal; while the ordinary mode is *paragenic*. One form of it is illustrated in Fig. 394. The middle portion had attained a length of half an inch or more, and then became geniculated simultaneously at either extremity. These geniculations are often repeated in rutile, and the ends of the crystal are thus bent into one another, and occasionally produce nearly regular prismatic forms.

This metagenic twinning is sometimes presented by the successive layers of deposition in a crystal, as in some quartz crystals, especially amethyst, the inseparable layers, exceedingly thin, being of opposite kinds. In a similar manner, crystals of the triclinic feldspars, albite, etc., are often made up of thin plates parallel to $b(010)$, by oscillatory composition, and the face $c(001)$, accordingly, is finely striated parallel to the edge c/b.

241. Repeated Twinning, Polysynthetic and Symmetrical. — In the preceding paragraph one case of repeated twinning has been mentioned, that of the feldspars; it is a case of *parallel* repetition or parallel grouping in reversed position of successive crystalline lamellæ. This kind of twinning is often called *polysynthetic twinning*, the lamellæ in many cases being extremely thin, and giving rise to a series of parallel lines (striations) on a crystal face or a surface of cleavage. The triclinic feldspars show in many cases polysynthetic twinning and not infrequently on both *c*(001) and *b*(010), cf. p. 172. It is also observed with magnetite (Fig. 474), pyroxene, barite, etc.

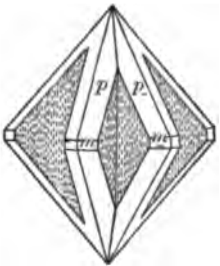
Another kind of repeated twinning is illustrated by Figs. 395–400, where the successively reversed individuals are not parallel. In these cases the axes may, however, lie in a zone, as the prismatic twins of aragonite, or they may be inclined to each other, as in Fig. 397 of staurolite In all such cases the repetition of the twinning tends to produce circular forms, when the angle between the two axial systems is an aliquot part of 360° (approximately). Thus six-rayed twinned crystals, consisting of three individuals (hence called *trillings*), occur with chrysoberyl (Fig. 395), or cerussite (Fig. 396), or staurolite (Fig. 397), since three times the angle of twinning in each case is not far from 360°. Again, five-fold twins, or *fivelings*, occur in the octahedrons of gold and spinel (Fig 398), since 5 × 70° 32′ = 360° (approx.). Eight-fold twins, or *eightlings*, of rutile (Figs. 399, 413) occur, since the angle of the axes in twinned position goes approximately eight times in 360°.

395



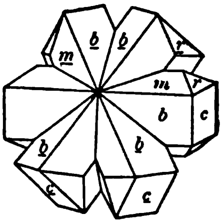
Chrysoberyl

396



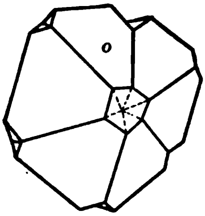
Cerussite

397



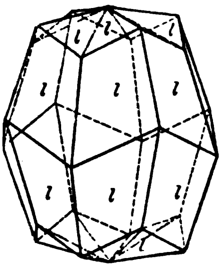
Staurolite

398



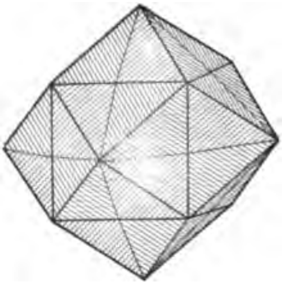
Spinel

399



Rutile

400



Phillipsite

Repeated twinning of the symmetrical type often serves to give the compound crystal an apparent symmetry of higher grade than that of the simple individual, and the result is often spoken of as a kind of pseudo-symmetry (Art. **20**), cf. Fig. 431 of aragonite, which represents a basal section of a *pseudo-hexagonal* crystal. Fig. 400 of phillipsite (cf. Figs. 452–454) is an interesting case, since it shows how a multiple twin of a monoclinic crystal may simulate an isometric crystal (dodecahedron).

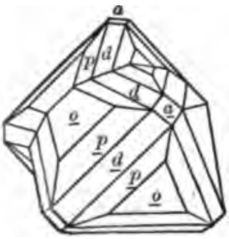
Compound crystals in which twinning exists in accordance with two laws at once are not of common occurrence; an excellent example is afforded by staurolite, Fig. 441. They have also been observed with albite, orthoclase, and in other cases.

242. Secondary Twinning. — When there is reason to believe that the twinning has been produced subsequently to the original formation of the crystal, or crystalline mass, as, for example, by pressure, it is said to be *secondary*. Thus the calcite grains of a crystalline limestone often show such secondary twinning lamellæ. The same are occasionally observed (||c, 001) in pyroxene crystals. Further, the polysynthetic twinning of the triclinic feldspars is often secondary in origin. This subject is further discussed on a later page, where it is also explained that in certain cases twinning may be produced artificially in a crystal individual — *e.g.*, in calcite (see Art. 282).

EXAMPLES OF IMPORTANT METHODS OF TWINNING

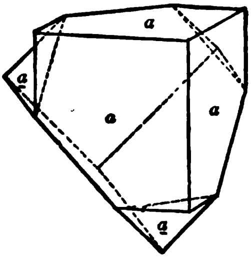
243. Isometric System. — With few exceptions the twins of the normal class of this system are of one kind, the twinning-axis an octahedral axis, and the twinning-plane consequently parallel to an *octahedral face;* in most cases, also, the latter coincides with the composition-plane. Fig. 388, p. 161,* shows this kind as applied to the simple octahedron; it is especially common with the spinel group of minerals, and is hence called in general a *spinel-twin.*

401



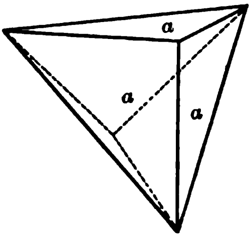
Galena

402



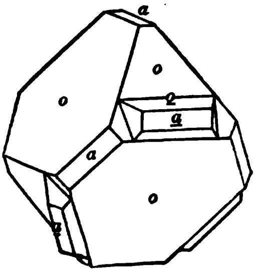
Copper

403



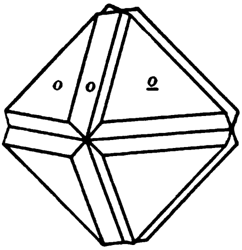
Copper

404



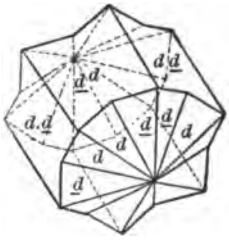
Galena

405



Haüynite

406



Sodalite

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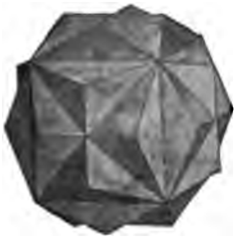
* It will be noted that here and elsewhere the letters used to designate the faces on the twinned parts of crystals are distinguished by a subscript line.

Fig. 401 is a similar more complex form; Fig. 402 shows a cube twinned by this method, and Fig. 403 represents the same form but shortened in the direction of the octahedral axis, and hence having the anomalous aspect of a triangular pyramid. All these cases are contact-twins.

Penetration-twins, following the same law, are also common. A simple case of fluorite is shown in Fig. 391, p. 163; Fig. 404 shows one of galena; Fig. 405 is a repeated octahedral twin of haüynite, and Fig. 406 a dodecahedral twin of sodalite.

407

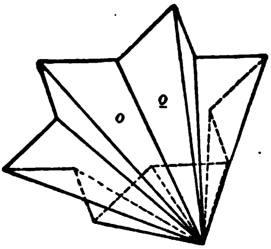


Pyrite

244. In the *pyritohedral class* of the isometric system penetration-twins of the type shown in Fig. 407 are common (this form of pyrite is often called the *iron cross*). Here the cubic axis is the twinning-axis, and obviously such a twin is impossible in the normal class.

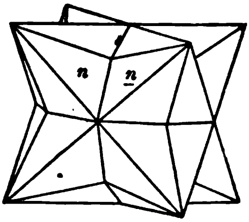
Figs. 408 and 409 show analogous forms with parallel axes for crystals belonging to the tetrahedral class. The peculiar development of Fig. 408 of tetrahedrite is to be noted. Fig. 410 is a twin of the ordinary spinel type of another tetrahedral species, sphalerite; with it, complex forms with repeated twinning are not uncommon and sometimes polysynthetic twin lamellæ are noted.

408



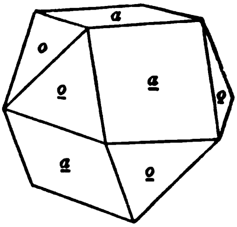
Tetrahedrite

409



Eulytite

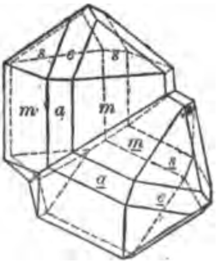
410



Sphalerite

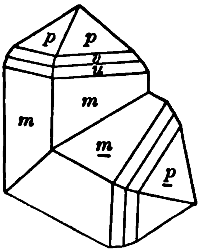
245. Tetragonal System. — The most common method is that where the twinning-plane is parallel to a face of the pyramid, $e(101)$. It is especially characteristic of the species of the rutile group — viz., rutile and cassiterite: also similarly the allied species zircon. This is illustrated in Fig. 411, and

411



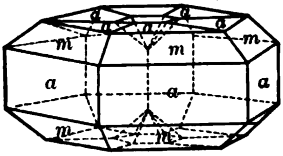
Cassiterite

412



Zircon

413



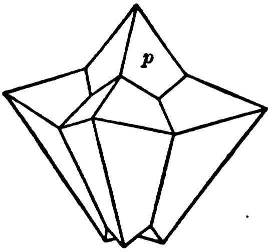
Rutile

again in Fig. 412. Fig. 413 shows a repeated twin of rutile, the twinning according to this law; the vertical axes of the successive six individuals lie in a plane, and an inclosed circle is the result. Another repeated twin of rutile according to the same law is shown in Fig. 399; here the successive vertical axes form a zigzag line; Fig. 414 shows an analogous twin of hausmannite.

Another kind of twinning with the twinning-plane parallel to a face of the pyramid (301) is shown in Fig. 415.

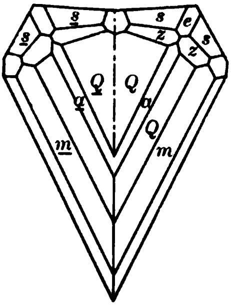
246. In the *pyramidal* class of the same system twins of the type of Fig. 416 are not rare. Here the vertical axis, *c*, is the twinning-axis; such a crystal may simulate one of the normal class.

414



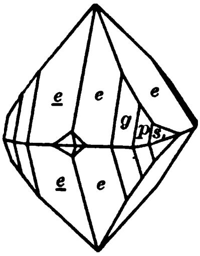
Hausmannite

415



Rutile

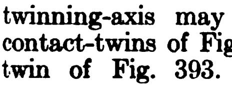
416



Scheelite

In chalcopyrite, of the *sphenoidal* class, twinning with a face of the unit pyramid, *f*(111), as the twinning-plane is common (Fig. 417). As the angles differ but a small fraction of a degree from those of a regular octahedron, such twins often resemble closely spinel-twins. The face *e*(101) may also be a twinning-plane and other rarer types have been noted.

417

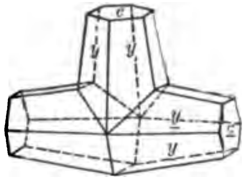


Chalcopyrite

247. Hexagonal System. — In the *hexagonal* division of this system twins are rare. An example is furnished by pyrrhotite, Fig. 418, where the twinning-plane is the pyramid $(10\bar{1}1)$, the vertical axes of the individual crystals being nearly at right angles to each other (since $0001 \wedge 10\bar{1}1 = 45° 8'$).

248. In the species belonging to the trigonal or *rhombohedral* division, twins are common. Thus the twinning-axis may be the vertical axis, as in the contact-twins of Figs. 419 and 420, or the penetration-twin of Fig. 393. Or the twinning-plane may be the obtuse rhombohedron $e(01\bar{1}2)$, as in Fig. 421, the vertical axes crossing at angles of $127\frac{1}{2}°$ and $52\frac{1}{2}°$. Again, the twinning-plane may be $r(10\bar{1}1)$, as in Figs. 422–425, the vertical axes nearly at right angles ($90\frac{3}{4}°$); or $(0\bar{2}21)$, as in Fig. 426, the axes inclined $53\frac{3}{4}°$ and $126\frac{1}{4}°$.

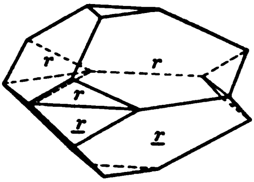
418



Pyrrhotite

In the *trapezohedral* class, the species quartz shows several methods of twinning. In Fig. 427 the twinning-plane is the pyramid $\xi(11\bar{2}2)$, the axes crossing at angles of $84\frac{1}{2}°$ and $95\frac{1}{2}°$. In Fig. 428 the twinning-axis is *c*, the axes hence parallel, the individuals both right- or both left-handed but unsymmetrical, $r(10\bar{1}1)$ then parallel to and coinciding with $z(01\bar{1}1)$. The re-

419



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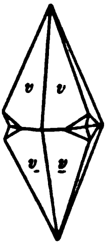

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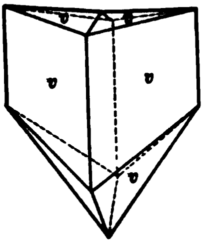

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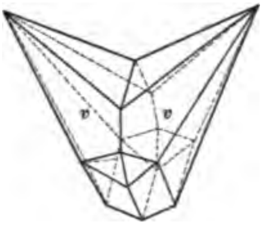

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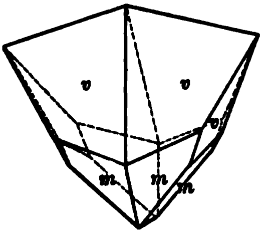

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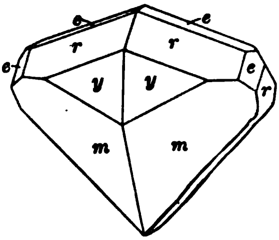

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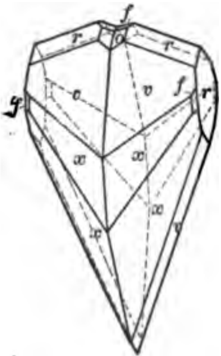

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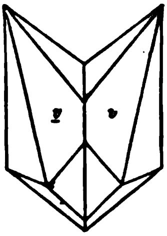
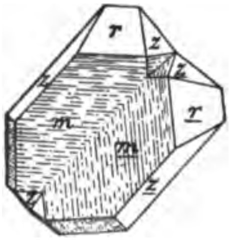


Figs. 419–426, Calcite

sulting forms, as in Fig. 428, are mostly penetration-twins, and the parts are often very irregularly united, as shown by dull areas (z) on the plus rhombohedral face (r); otherwise these twins are recognized by pyro-electrical phenomena. In Fig. 429 the twinning-plane is $a(11\bar{2}0)$ — the *Brazil law* — the individuals respectively right- and left-handed and the twin symmetrical with reference to an a-face; these are usually irregular penetration-twins; in these twins r and $\underline{r}$, also z and $\underline{z}$, coincide These twins often show, in con-

427



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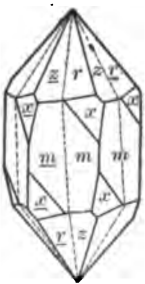

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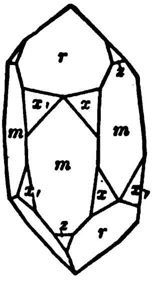
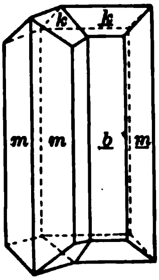


Figs. 427–429, Quartz

verging polarized light, the phenomenon of Airy's spirals. It may be added that pseudo-twins of quartz are common — that is, groups of crystals which *nearly* conform to some more or less complex twinning law, but where the grouping is nevertheless only accidental

249. Orthorhombic System. — In the orthorhombic system the commonest method of twinning is that where the twinning-plane is a face of a prism of 60°, or nearly 60°. This is well shown with the species of the aragonite group. In accordance with the principle stated in Art. **241,** the twinning after this law is often repeated, and thus forms with pseudo-hexagonal symmetry result. Fig. 430 shows a simple twin of aragonite; Fig. 431 shows a basal section of an aragonite triplet which although it resembles a hexagonal prism reveals its twinned character by the striations on the basal plane and by irregularities on its composite prism faces due to the fact that the prismatic angle is not exactly 60°. With witherite (and bromlite), apparent hexagonal pyramids are common, but the true complex twinning is revealed in polarized light, as noted later.

430



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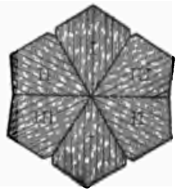
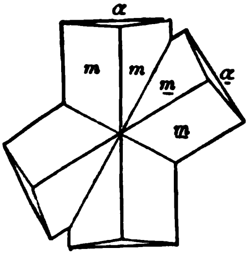


Aragonite

Twinning of the same type, but where a dome of 60° is twinning-plane, is common with arsenopyrite (tw. pl. $e(101)$), as shown in Figs. 432, 433; also

432



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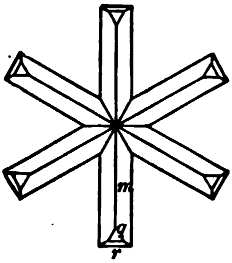
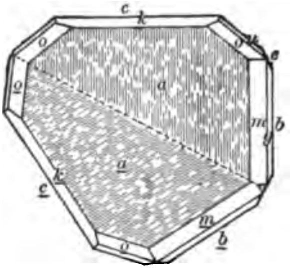


Arsenopyrite

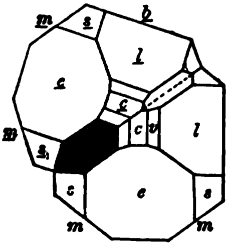
434



Columbite

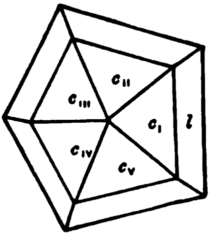
Fig. 434 of columbite, but compare Fig. 385 and remarks in Art **238**. Another example is given in Fig. 395 of alexandrite (chrysoberyl). Chrysolite, manganite, humite, are other species with which this kind of twinning is common.

435



Marcasite

436



Marcasite

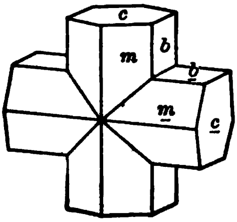
437

Arsenopyrite

Another common method of twinning is that where the twinning is parallel to a face of a prism of about 70½°, as shown in Fig. 435. With this method symmetrical fivelings not infrequently occur (Figs. 436, 437).

The species staurolite illustrates three kinds of twinning. In Fig. 438 the twinning-plane is (032), and since (001 ∧ 032) = 45° 41′, the crystals cross nearly at right angles. In Fig. 439 the twinning-plane is the prism (230). In Fig. 440 it is the pyramid (232); the crystals then crossing at angles of about 60°, stellate trillings occur (see Fig. 397), and indeed more complex forms. In Fig. 441 there is twinning according to both (032) and (232).

438



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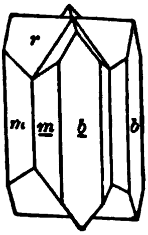

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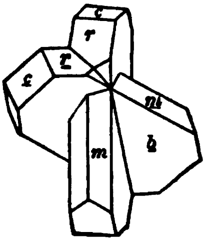
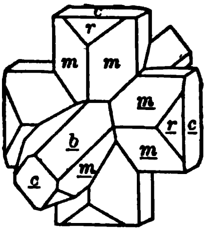


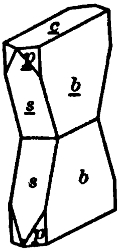
Staurolite

441



Staurolite

442

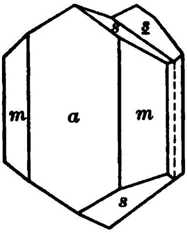


Struvite

In the hemimorphic class, twins of the type shown in Fig. 442, with *c*(001) as the twinning-plane, are to be noted.

250. Monoclinic System. — In the monoclinic system, twins with the vertical axis as twinning-axis are common; this is illustrated by Fig. 443 of augite (pyroxene), Fig. 444 of gypsum, and Fig. 445 of orthoclase (see also Fig. 390, p. 162). With the latter species these twins are called *Carlsbad twins* (because common in the trachyte of Carlsbad, Bohemia); they may be contact-twins

443



Augite

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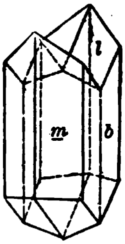

Gypsum

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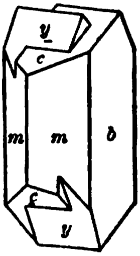
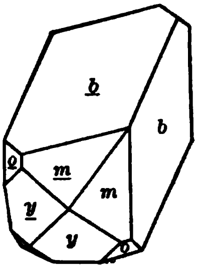


Orthoclase

(Fig. 390), or irregular penetration-twins (Fig. 445). In Fig. 390 it is to be noted that c and x fall nearly in the same plane.

In Fig. 446, also of orthoclase, the twinning-plane is the clinodome (021), and since $(001 \wedge 021) = 44° 56\frac{1}{2}'$, this method of twinning yields nearly square prisms. These twins are called *Baveno twins* (from a prominent locality at Baveno, Italy); they are often repeated (Fig. 447). In Fig. 448 a *Manebach twin* is shown; here the twinning-plane is $c(001)$. Other rarer types of twinning have been noted with orthoclase. Polysynthetic twinning with $c(001)$ as twinning-plane is common with pyroxene (cf. Fig. 461, p. 173).

446



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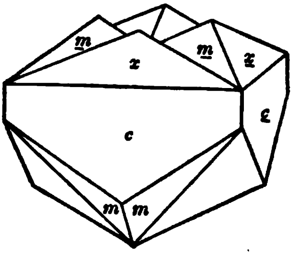

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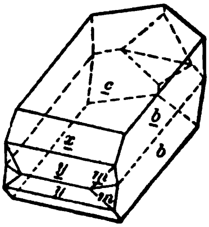
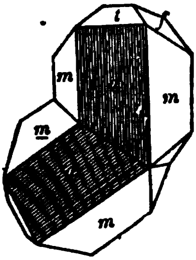


Orthoclase

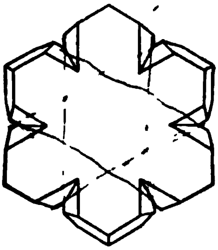
Twins of the aragonite-chrysoberyl type are not uncommon with monoclinic species, having a prominent 60° prism (or dome), as in Fig. 449. Stellate twins after this law are common with chondrodite and clinohumite. An analogous twin of pyroxene is shown in Fig. 450; here the pyramid $(\bar{1}22)$ is the twinning-plane, and since $(010 \wedge \bar{1}22) = 59° 21'$, the crystals cross at angles of nearly 60°; further, the orthopinacoids fall nearly in a common zone, since $(100 \wedge \bar{1}22) = 90° 9'$. In Fig. 451 the twinning-plane is the orthodome (101). Phillipsite and harmotome exhibit multiple twinning, and the crystals often show pseudo-symmetry. Fig. 452 shows a cruciform fourling with $c(001)$ as twinning-plane, the twinning shown by the striations on the side face. This is compounded in Fig. 453 with twinning-plane (011), making nearly square prisms, and this further repeated with $m(110)$ as twinning-plane

449



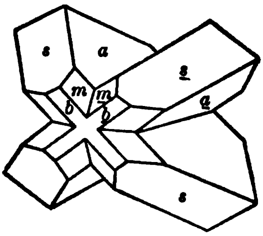
Wolframite

450



Pyroxene

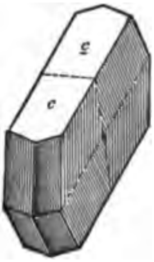
451



Pyroxene

yields the form in Fig. 454, or even Fig. 400, p. 164, resembling an isometric dodecahedron, each face showing a fourfold striation.

452



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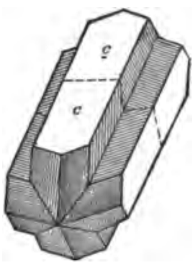

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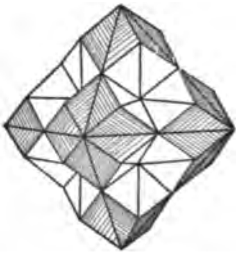
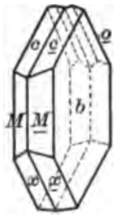


Phillipsite

251. Triclinic System. — The most interesting twins of the triclinic system are those shown by the feldspars. Twinning with $b(010)$ as the twinning-plane is very common, especially polysynthetic twinning yielding thin parallel lamellæ, shown by the striations on the face c (or the corresponding cleavage-surface), and also clearly revealed in polarized light. This is known as the *albite law* (Figs. 455, 456). Another important method (Fig. 457) is that of the *pericline law;* the twinning-axis is the crystallographic axis b. Here the twins are united by a section (rhombic section) shown in the figure and further explained under the feldspars. Polysynthetic twinning after this law is common, and hence a cleavage-mass may show two sets of striations, one on the surface parallel to $c(001)$ and the other on that parallel to $b(010)$. The angle made by these last striations with the edge 001/010 is characteristic of the particular triclinic species, as noted later.

455



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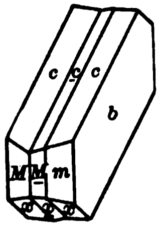

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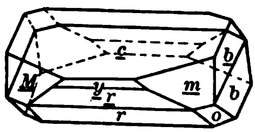
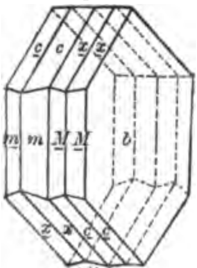


Albite

Twins of albite of other rarer types also occur, and further twins similar to the Carlsbad, Baveno, and Manebach twins of orthoclase. Fig. 458 shows twinning according to both the albite and Carlsbad types.

458



Albite

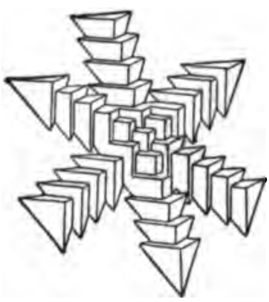
REGULAR GROUPING OF CRYSTALS

252. Parallel Grouping. — Connected with the subject of twin crystals is that of the parallel position of associated crystals of the same species, or of different species.

Crystals of the same species occurring together are very commonly in parallel position. In this way large crystals, as of calcite, quartz, fluorite, are sometimes built up of smaller individuals grouped together with corresponding faces parallel. This parallel grouping is often seen in crystals as they lie on the supporting rock. On glancing the eye over a surface covered with crystals a reflection from one face will often be accompanied by reflections from the corresponding face in each of the other crystals, showing that the crystals are throughout similar in their positions.

With many species, complex crystalline forms result from the growth of parallel partial crystals in the direction of the crystallographic axes, or axes of symmetry. Thus *dendritic* forms, resembling branching vegetation, often of great delicacy, are seen with gold, copper, argentite, and other species, especially those of the isometric system. This is shown in Fig. 459 (ideal), and again in Fig. 460, where the twinned and flattened cubes (cf. Fig. 403, p. 165) are grouped in directions corresponding to the diagonals of an octahedral face which is the twinning-plane.

459

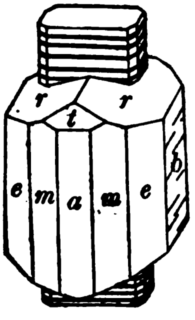


460

Copper

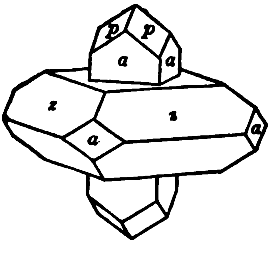
253. Parallel Grouping of Unlike Species. — Crystals of different species often show the same tendency to parallelism in mutual position. This is true most frequently of species which are more or less closely similar in form and composition. Crystals of albite, implanted on a surface of orthoclase, are sometimes an example of this; crystals of amphibole and pyroxene (Fig. 461), of zircon and xenotime (Fig. 462), of various kinds of mica, are also at times observed associated in parallel position.

461



Amphibole enclosing pyroxene in parallel position

462



Xenotime enclosing zircon in parallel position

The same relation of position also occasionally occurs where there is no connection in composition, as the crystals of rutile on tabular crystals of hematite, the vertical axes of the former coinciding with the horizontal axes of the latter. Crystals of calcite have been observed whose rhombohedral faces had a series of quartz crystals upon them, all in parallel position; sometimes three such quartz crystals, one on each rhombohedral face, entirely envelop the calcite, and unite with re-entering angles to form pseudo-twins (rather trillings) of quartz after calcite. Parallel growths of the sphenoidal chalcopyrite upon the tetrahedral sphalerite are common, the similarity in crystal structure of the two species controlling the position of the crystals of chalcopyrite.

IRREGULARITIES OF CRYSTALS

254. The laws of crystallization, when unmodified by extrinsic causes, should produce forms of exact geometrical symmetry, the angles being not only equal, but also the homologous faces of crystals and the dimensions in the directions of like axes. This symmetry is, however, so uncommon that it can hardly be considered other than an ideal perfection. The various possible kinds of symmetry, and the relation of this ideal geometrical symmetry to the actual crystallographic symmetry, have been discussed in Arts. **14** and **18** *et seq.* Crystals are very generally distorted, and often the fundamental forms are so completely disguised that an intimate familiarity with the possible irregularities is required in order to unravel their complexities. Even the angles may occasionally vary rather widely.

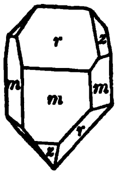
The irregularities of crystals may be treated under several heads: 1, *Variations of form and dimensions;* 2, *Imperfections of surface;* 3, *Variations of angles;* 4, *Internal imperfections and impurities.*

1. VARIATIONS IN THE FORMS AND DIMENSIONS OF CRYSTALS

255. Distortion in General. — The variations in the forms of crystals, or, in other words, their *distortion*, may be *irregular* in character, certain faces being larger and others smaller than in the ideal geometrical solid. On the other hand, it may be *symmetrical*, giving to the distorted form the symmetry of a group or system different from that to which it actually belongs. The former case is the common rule, but the latter is the more interesting.

256. Irregular Distortion. — As stated above and on p. 13, all crystals show to a greater or less extent an irregular or accidental variation from the ideal geometrical form. This distortion, if not accompanied by change in the interfacial angles, has no particular significance, and does not involve any deviation from the laws of crystallographic symmetry. Figs. 463, 464 show distorted crystals of quartz; they may be compared with the ideal form, Fig. 284, p. 113. Fig. 465 is an ideal and Fig. 466 an actual crystal of lazulite.

463



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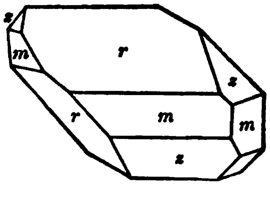

Quartz

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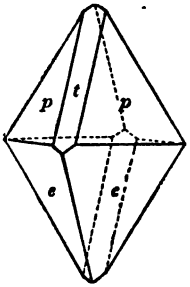

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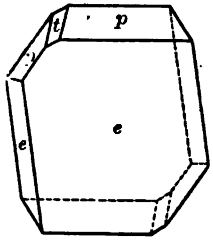


Lazulite

The correct identification of the forms on a crystal is rendered much more difficult because of this prevailing distortion, especially when it results in the entire *obliteration* of certain faces by the enlargement of others. In deciphering the distorted crystalline forms it must be remembered that while the appearance of the crystals may be entirely altered, the interfacial angles remain the same; moreover, like faces are physically alike — that is, alike in degree of luster, in striations, and so on. Thus the prismatic faces of quartz show almost always characteristic horizontal striations.

In addition to the variations in form which have just been described, still greater irregularities are due to the fact that, in many cases, crystals in nature are attached either to other crystals or to some rock surface, and in consequence of this are only partially developed. Thus quartz crystals are generally attached by one extremity of the prism, and hence have only one set of pyramidal faces; perfectly formed crystals, having the double pyramid complete, are rare.

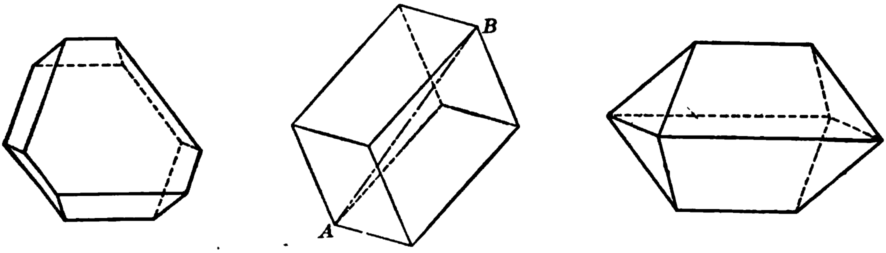
257. Symmetrical Distortion. — The most interesting examples of the symmetrical distortion of crystalline forms are found among crystals of the isometric system. An elongation in the direction of one cubic axis may give the appearance of tetragonal symmetry, or that in the direction of two cubic axes of orthorhombic symmetry; while in the direction of an octahedral axis a lengthening or shortening gives rise to forms of apparent rhombohedral symmetry. Such cases are common with native gold, silver, and copper.

A *cube* lengthened or shortened along one axis becomes a right square prism, and if varied in the direction of two axes is changed to a rectangular prism. Cubes of pyrite, galena, fluorite, etc., are often thus distorted. It is very unusual to find a cubic crystal that is a true symmetrical cube. In some species the cube or octahedron (or other isometric form) is lengthened into a capillary crystal or needle, as happens in cuprite and pyrite.

An octahedron *flattened* parallel to a face — that is, in the direction of a trigonal symmetry axis is reduced to a tabular crystal resembling a rhombohedral crystal with basal plane (Fig. 467). If *lengthened* in the same direction (*i.e.* along line A–B, Fig. 468), to the obliteration of the terminal octahedral faces, it becomes an acute rhombohedron.

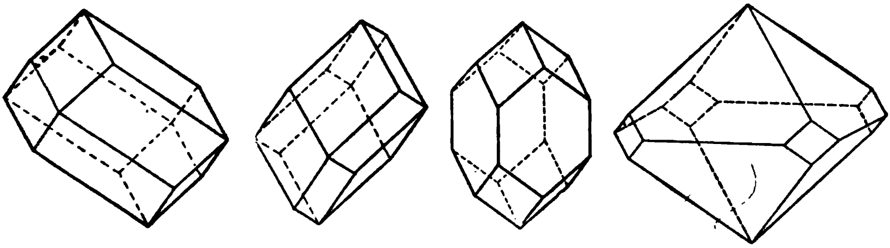
When an octahedron is extended in the direction of a line between two opposite edges, or that of a binary symmetry axis, it has the general form of a rectangular octahedron; and still farther extended, as in Fig. 469, it resembles a combination of two orthorhombic domes (spinel, fluorite, magnetite).

467 468 469



Distorted Octahedrons

470 471 472 473



Distorted Dodecahedrons

The *dodecahedron* lengthened in the direction of a trigonal symmetry axis becomes a six-sided prism with three-sided summits, as in Fig. 470. If shortened in the same direction, it becomes a *short* prism of the same kind (Fig. 471). Both resemble rhombohedral forms and are common in garnet. When lengthened in the direction of one of the cubic axes, the dodecahedron becomes a square prism with pyramidal summits (Fig. 472), and shortened along the same axis it is reduced to a square octahedron, with truncated angles (Fig. 473).

The trapezohedron elongated in the direction of an octahedral (trigonal) axis assumes rhombohedral (trigonal) symmetry.

If the elongation of the trapezohedron takes place along a cubic axis, it becomes a double eight-sided pyramid with four-sided summits; or if these summit planes are obliterated by a farther extension, it becomes a complete eight-sided double pyramid.

Similarly the trisoctahedron, tetrahexahedron and hexoctahedron may show distortion of the same kind. Further examples are to be found in the other systems.

2. IMPERFECTIONS OF THE SURFACES OF CRYSTALS

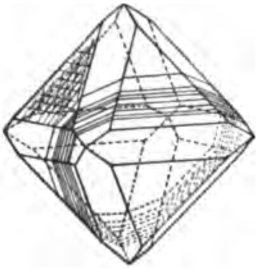
258. Striations Due to Oscillatory Combinations. — The parallel lines or furrows on the surfaces of crystals are called *striæ* or *striations*, and such surfaces are said to be *striated.*

Each little ridge on a striated surface is inclosed by two narrow planes more or less regular. These planes often correspond in position to different faces of the crystal, and these ridges have been formed by a continued oscillation in the operation of the causes that give rise, when acting uninterruptedly, to enlarged faces. By this means, the surfaces of a crystal are marked in parallel lines, with a succession of narrow planes meeting at an angle and constituting the ridges referred to.

This combination of different planes in the formation of a surface has been termed *oscillatory combination.* The horizontal striations on prismatic crystals of quartz are examples of this combination, in which the oscillation has taken place between the prismatic and rhombohedral faces. Thus crystals of quartz are often tapered to a point, without the usual pyramidal terminations.

Other examples are the striations on the cubic faces of pyrite parallel to the intersections of the cube with the faces of the pyritohedron; also the striations on magnetite due to the oscillation between the octahedron and dodecahedron. Prisms of tourmaline are very commonly bounded vertically by three convex surfaces, owing to an oscillatory combination of the faces in the prismatic zone.

474



Magnetite

259. Striations Due to Repeated Twinning. — The striations of the basal plane of albite and other triclinic feldspars, also of the rhombohedral surfaces of some calcite, have been explained in Art. **241** as due to polysynthetic twinning. This is illustrated by Fig. 474 of magnetite from Port Henry, N. Y. (Kemp.)

260. Markings from Erosion and Other Causes. — The faces of crystals are often uneven, or have the crystalline structure developed as a consequence of etching by some chemical agent. Cubes of galena are frequently thus uneven, and crystals of lead sulphate (anglesite) or lead carbonate (cerussite) are sometimes present as evidence with regard to the cause. Crystals of numerous other species, even of corundum, spinel, quartz, etc., sometimes show the same result of partial change over the surface — often the incipient stage in a process tending to a final removal of the whole crystal. Interesting investigations have been made by various authors on the action of solvents on different minerals, the actual structure of the crystals being developed in this way. This method of etching is fully discussed, with illustrations, in another place (Art. 286).

The markings on the surfaces of crystals are not, however, always to be ascribed to etching. In most cases such depressions, as well as the minute elevations upon the faces having the form of low pyramids (so-called *vicinal* prominences), are a part of the original molecular growth of the crystal, and often serve to show the successive stages in its history. They may be imperfections arising from an interrupted or disturbed development of the form, the perfectly smooth and even crystalline faces being the result of completed action free from disturbing causes. Examples of the markings referred to occur on the crystals of most minerals, and conspicuously so on the rhombohedral faces of quartz.

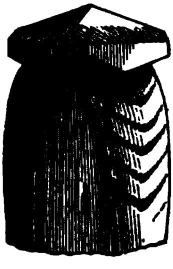
Faces of crystals are often marked with angular elevations more or less distinct, which are due to oscillatory combination. Octahedrons of fluorite are common which have for each face a surface of minute cubes, proceeding from an oscillation between the cube and octahedron. Sometimes an examination of such a crystal shows that though the form is apparently octahedral, there are no octahedral faces present at all. Other similar cases could be mentioned.

Whatever their cause, these minute markings are often of great importance as revealing the true molecular symmetry of the crystal. For it follows from the symmetry of crystallization that like faces must be physically alike — that is, in regard to their surface character; it thus often happens that on all the crystals of a species from a given locality, or perhaps from all localities, the same planes are etched or roughened alike. There is much uniformity on the faces of quartz crystals in this respect.

261. Curved surfaces may result from (*a*) oscillatory combination; or (*b*) some independent molecular condition producing curvatures in the laminæ of the crystal; or (*c*) from a mechanical cause.

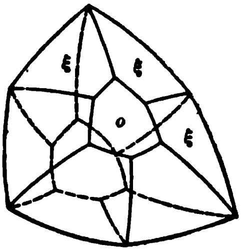
Curved surfaces of the *first* kind have been already mentioned (Art. 258). A singular curvature of this nature is seen in Fig. 475, of calcite; in the lower part traces of a scalenohedral form are apparent which was in oscillatory combination with the prismatic form.

475



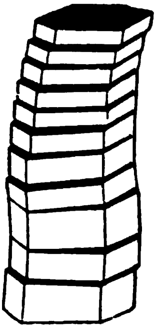
Calcite

476



Diamond

477



Beryl

Curvatures of the *second* kind sometimes have all the faces convex. This is the case in crystals of diamond (Fig. 476), some of which are almost spheres. The mode of curvature, in which all the faces are equally convex, is less common than that in which a convex surface is opposite and parallel to a corresponding concave surface. Rhombohedrons of dolomite and siderite are usually thus curved. The feathery curves of frost on windows and the flagging-stones of pavements in winter are other examples. The alabaster rosettes from the Mammoth Cave, Kentucky, are similar. Stibnite crystals sometimes show very remarkable curved and twisted forms.

A *third* kind of curvature is of *mechanical origin.* Sometimes crystals appear as if they had been broken transversely into many pieces, a slight displacement of which has given a curved form to the prism. This is common in tourmaline and beryl. The beryls of Monroe, Conn., often present these interrupted curvatures, as represented in Fig. 477.

Crystals not infrequently occur with a deep pyramidal depression occupying the place of each plane, as is often observed in common salt, alum, and sulphur. This is due in part to their rapid growth.

3. VARIATIONS IN THE ANGLES OF CRYSTALS

262. The greater part of the distortions described in Arts **256, 257** occasion no change in the interfacial angles of crystals. But those imperfections that produce convex, curved, or striated faces necessarily cause such variations. Furthermore, circumstances of heat or pressure under which the crystals were formed may sometimes have resulted not only in distortion of form, but also some variation in angle. The presence of impurities at the time of crystallization may also have a like effect.

Still more important is the change in the angles of completed crystals which is caused by subsequent pressure on the matrix in which they were formed, as, for example, the change which may take place during the more or less complete metamorphism of the inclosing rock.

The change of composition resulting in pseudomorphous crystals (see Art. **273**) is generally accompanied by an irregular change of angle, so that the pseudomorphs of a species vary much in angle.

In general it is safe to affirm that, with the exception of the irregularities arising from imperfections in the process of crystallization, or from the subsequent changes alluded to, variations in angles are rare, and the constancy of angle alluded to in Art. **11** is the universal law.

In cases where a greater or less variation in angle is observed in the crystals of the same species from different localities, the cause for this can usually be found in a difference of chemical composition. In the case of isomorphous compounds it is well known that an exchange of corresponding chemically equivalent elements may take place without a change of form, though usually accompanied with a slight variation in the fundamental angles.

The effect of heat upon the form of crystals is alluded to in Art. **433.**

4. INTERNAL IMPERFECTIONS AND INCLUSIONS

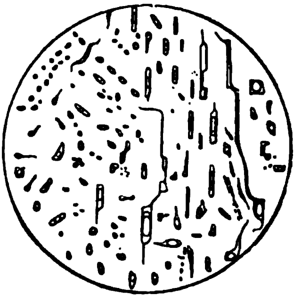
263. The transparency of crystals is often destroyed by disturbed crystallization; by impurities taken up from the solution during the process of crystallization; or, again, by the presence of foreign matter resulting from partial chemical alteration. The general name, *inclusion*, is given to any foreign body inclosed within the crystal, whatever its origin. These inclusions are extremely common; they may be gaseous, liquid, or solid; visible to the unaided eye or requiring the use of the microscope.

Rapid crystallization is a common explanation of inclusions. This is illustrated by quartz crystals containing large cavities full or nearly full of water (in the latter case, these showing a movable bubble); or, they may contain sand or iron oxide in large amount. In the case of calcite, crystallization from a liquid largely charged with a foreign material, as quartz sand, may result in the formation of crystals in which the impurity makes up as much as two-thirds of the whole mass; this is seen in the famous Fontainebleau limestone, and similarly in that from other localities.

264. Liquid and Gas Inclusions. — Attention was early called by Brewster to the presence of fluids in cavities in certain minerals, as quartz, topaz, beryl, chrysolite, etc. In later years this subject has been thoroughly studied by Sorby, Zirkel, Vogelsang, Fischer, Rosenbusch, and others. The nature of the liquid can often be determined, by its refractive power, or by special physical test (*e.g.*, determination of the critical point in the case of CO_2), or by chemical examination. In the majority of cases the observed liquid is simply water; but it may be the salt solution in which the crystal was formed, and not infrequently, especially in the case of quartz, liquid carbon dioxide (CO_2), as first proved by Vogelsang. These liquid inclusions are marked as such, in many cases, by the presence in the cavity of a movable bubble of gas. Occasionally cavities contain two liquids, as water and liquid carbon dioxide, the latter then inclosing a bubble of the same substance as gas (cf. Fig. 478). Interesting experiments can be made with sections showing such inclusions (cf. literature, p. 181). The mixture of gases yielded by smoky quartz, meteoric iron, and other substances, on the application of heat, has been analyzed by Wright.

In some cases the cavities appear to be empty; if they then have a regular form determined by the crystallization of the species, they are often called *negative crystals*. Such cavities are commonly of secondary origin, as remarked on a later page.

478



Beryllonite

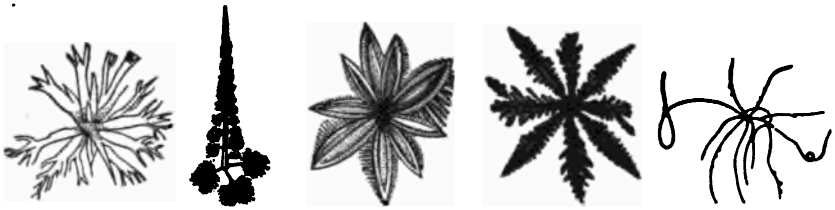
265. Solid Inclusions. — The solid inclusions are almost infinite in their variety. Sometimes they are large and distinct, and can be referred to known mineral species, as the scales of göthite or hematite, to which the peculiar character of aventurine feldspar is due. Magnetite is a very common impurity in many minerals, appearing, for example, in the Pennsbury mica; quartz is also often mechanically mixed, as in staurolite and gmelinite. On the other hand, quartz crystals very commonly inclose foreign material, such as chlorite, tourmaline, rutile, hematite, asbestus, and many other minerals. (Cf. also Arts. **266, 267.**)

The inclusions may consist of a heterogeneous mass of material; as the granitic matter seen in orthoclase crystals in a porphyritic granite; or the feldspar, quartz, etc., sometimes inclosed in large coarse crystals of beryl or spodumene, occurring in granite veins.

266. Microlites, Crystallites. — The microscopic crystals observed as inclusions may sometimes be referred to known species, but more generally their true nature is doubtful. The term *microlites*, proposed by Vogelsang, is often used to designate the minute inclosed crystals; they are generally of needlelike form, sometimes quite irregular, and often very remarkable in their arrangement and groupings; some of them are exhibited in Fig. 484 and Fig. 485, as explained below. Where the minute individuals belong to known species they are called, for example, feldspar microlites, etc.

Crystallites is an analogous term used by Vogelsang to cover those minute forms which have not the regular exterior form of crystals, but may be considered as intermediate between amorphous matter and true crystals. Some of the forms are shown in Figs. 479–483; they are often observed in glassy volcanic rocks, and also in furnace-slags. A series of names has been given to varieties of crystallites, such as globulites, margarites, etc. Trichite and belonite are names introduced by Zirkel; the former name is derived from *θρίξ, hair;* trichites, like that in Fig. 483, are common in obsidian.

479 480 481 482 483

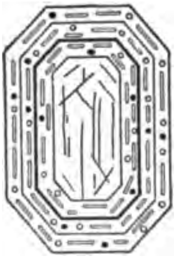


Crystallites

The microscopic inclusions may also be of an irregular glassy nature; this kind is often observed in crystals which have formed from a molten mass, as lava or the slag of an iron furnace.

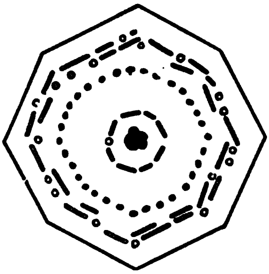
267. Symmetrically Arranged Inclusions. — In general, while the solid inclusions sometimes occur quite irregularly in the crystals, they are more generally arranged with some evident reference to the symmetry of the form, or external faces of the crystals. Examples of this are shown in the following figures. Fig. 484 exhibits a crystal of augite, inclosing magnetite, feldspar and nephelite microlites, etc. Fig. 485 shows a crystal of leucite, a species

484



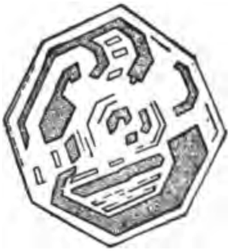
Augite (Zirkel)

485



Leucite (Zirkel)

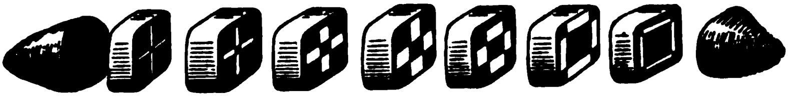
486



Garnet inclosing quartz (Heddle)

whose crystals very commonly inclose foreign matter. Fig. 486 shows a section of a crystal of garnet, containing quartz.

487



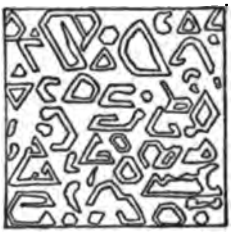
Andalusite

Another striking example is afforded by andalusite (Fig. 487), in which the inclosed carbonaceous impurities are of considerable extent and remarkably arranged, so as to yield symmetrical figures of various forms. Staurolite occasionally shows analogous carbonaceous impurities symmetrically distributed.

The magnetite common as an inclusion in muscovite, alluded to above, is always symmetrically disposed, usually parallel to the directions of the percussion-figure (Fig. 491, p. 189). The asterism of phlogopite is explained by the presence of symmetrically arranged inclusions (cf. Art. **368**).

Fig. 488 shows an interesting case of symmetrically arranged inclusions due to chemical alteration. The original mineral, spodumene, from Branchville, Conn., has been altered to a substance apparently homogeneous to the eye, but found under the microscope to have the structure shown in Fig. 488. Chemical analysis proves the base to be albite and the inclosed hexagonal mineral to be a lithium silicate ($LiAlSO_4$) called eucryptite. It has not yet been identified except in this form.

488



Eucryptite in Albite

LITERATURE

Some of the most important works on the subject of microscopic inclusions are referred to here; for a fuller list of papers reference may be made to the work of Rosenbusch (1904); also that of Zirkel and others mentioned on pp. 3 and 4.

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CRYSTALLINE AGGREGATES

268. The greater part of the specimens or masses of minerals that occur may be described as aggregations of imperfect crystals. Many specimens whose structure appears to the eye quite homogeneous, and destitute internally of distinct crystallization, can be shown to be composed of crystalline grains. Under the above head, consequently, are included all the remaining varieties of structure among minerals.

The individuals composing imperfectly crystallized individuals may be:

1. *Columns, or fibers,* in which case the structure is *columnar or fibrous.*
2. *Thin laminæ,* producing a *lamellar* structure.
3. *Grains,* constituting a *granular* structure.

269. Columnar and Fibrous Structure. — A mineral possesses a *columnar* structure when it is made up of slender columns, as some amphibole. When the individuals are flattened like a knife-blade, as in cyanite, the structure is said to be *bladed.*

The structure again is called *fibrous* when the mineral is made up of fibres, as in asbestus, also the satin-spar variety of gypsum. The fibres may or may not be *separable.* There are many gradations between coarse columnar and fine fibrous structures. Fibrous minerals have often a silky luster.

The following are properly varieties of columnar or fibrous structure:

Reticulated: when the fibers or columns cross in various directions and produce an appearance having some resemblance to a net.

Stellated: when they radiate from a center in all directions and produce star-like forms. Ex. stilbite, wavellite.

Radiated, divergent: when the crystals radiate from a center without producing stellar forms. Ex. quartz, stibnite.

270. Lamellar Structure. — The structure of a mineral is *lamellar* when it consists of plates or leaves. The laminæ may be curved or straight, and thus give rise to the *curved* lamellar and *straight* lamellar structure. Ex. wollastonite (tabular spar), some varieties of gypsum, talc, etc. If the plates are approximately parallel about a common center the structure is said to be *concentric.* When the laminæ are thin and separable, the structure is said to be *foliaceous* or *foliated.* Mica is a striking example, and the term *micaceous* is often used to describe this kind of structure.

271. Granular Structure. — The particles in a granular structure differ much in size. When coarse, the mineral is described as *coarse-granular;* when fine, *fine-granular;* and if not distinguishable by the naked eye, the structure is termed *impalpable.* Examples of the first may be observed in granular crystalline limestone, sometimes called *saccharoidal;* of the second, in some varieties of hematite; of the last, in some kinds of sphalerite.

The above terms are indefinite, but from necessity, as there is every degree of fineness of structure among mineral species, from perfectly impalpable, through all possible shades, to the coarsest granular. The term *phanero-crystalline* has been used for varieties in which the grains are distinct, and *crypto-crystalline* for those in which they are not discernible, although an indistinct crystalline structure can be proved by the microscope.

Granular minerals, when easily crumbled in the fingers, are said to be *friable.*

272. Imitative Shapes. — The following are important terms used in describing the imitative forms of massive minerals.

Reniform: kidney-shaped. The structure may be radiating or concentric. Ex. hematite.

Botryoidal: consisting of a group of rounded prominences. The name is derived from the Greek *βότρυς*, a bunch of grapes. Ex. limonite, chalcedony, prehnite.

Mammillary: resembling the botryoidal, but composed of larger prominences. Ex. malachite.

Globular: spherical or nearly so; the globules may consist of radiating fibres or concentric coats. When attached, as they usually are, to the surface of a rock, they are described as *implanted globules.*

Nodular: in tuberose forms, or having irregular protuberances over the surface.

Amygdaloidal: almond-shaped, applied often to a rock (as diabase) containing almond-shaped or sub-globular nodules.

Coralloidal: like coral, or consisting of interlaced flexuous branchings of a white color, as in the variety of aragonite called *flos ferri.*

Dendritic: branching tree-like, as in crystallized gold. The term *dendrites* is used for similar forms even when not crystalline, as in the dendrites of manganese oxide, which form on surfaces of limestone or are inclosed in "moss-agates."

Mossy: like moss in form or appearance.

Filiform or *Capillary:* very slender and long, like a thread or hair; consists ordinarily of a succession of minute crystals. Ex. millerite.

Acicular: slender and rigid, like a needle. Ex. stibnite.

Reticulated: net-like. See Art. **269.**

Drusy: closely covered with minute implanted crystals. Ex. quartz.

Stalactitic: when the mineral occurs in pendent columns, cylinders, or elongated cones. Stalactites are produced by the percolation of water, holding mineral matter in solution, through the rocky roofs of caverns. The evaporation of the water produces a deposit of the mineral matter, and gradually forms a long pendent cylinder or cone. The internal structure may be imperfectly crystalline and granular, or may consist of fibres radiating from the central column, or there may be a broad cross-cleavage. The most familiar example of stalactites is afforded by calcite. Chalcedony, gibbsite, limonite, and some other species, also present stalactitic forms.

The term *amorphous* is used when a mineral has not only no crystalline form or imitative shape, but does not polarize the light even in its minute particles, and thus appears to be destitute wholly of a crystalline structure internally, as most opal. Such a structure is also called *colloid* or jelly-like, from the Greek *κόλλα* (see p. 8), for glue. The word amorphous is from *ἄ privative, and μόρφη, shape.*

273. Pseudomorphous Crystals. — Every mineral species has, when distinctly crystallized, a definite and characteristic form. Occasionally, however, crystals are found that have the form, both as to angles and general habit, of a certain species, and yet differ from it entirely in chemical composition. Moreover, it is often noted in such cases that, though in outward form complete crystals, in internal structure they are granular, or waxy, and have no regular cleavage. Even if they are crystalline in structure the optical characters do not conform to those required by the symmetry of the faces.

Such crystals are called *pseudomorphs*, and their existence is explained by the assumption, often admitting of direct proof, that the original mineral has been changed into the new compound; or it has disappeared through some agency, and its place been taken by another chemical compound to which the form does not belong. In all these cases the new substance is said to be a *pseudomorph after* the orginal mineral.

Common illustrations of pseudomorphous crystals are afforded by malachite in the form of cuprite, limonite in the form of pyrite, barite in the form of quartz, etc. This subject is further discussed in the chapter on Chemical Mineralogy.

PART II. PHYSICAL MINERALOGY

274. The PHYSICAL CHARACTERS of minerals fall under the following heads:

I. Characters depending upon *Cohesion* and *Elasticity* — viz., cleavage, fracture, tenacity, hardness, elasticity, etc.

II. *Specific Gravity*, or the *Density* compared with that of water.

III. Characters depending upon *Light* — viz., color, luster, degree of transparency, special optical properties, etc.

IV. Characters depending upon *Heat* — viz., heat-conductivity, change of form and of optical characters with change of temperature, fusibility, etc.

V. Characters depending upon *Electricity* and *Magnetism*.

VI. Characters depending upon the action of the senses — viz., taste, odor, feel.

275. General Relation of Physical Characters to Molecular Structure. — It has been stated on pp. 7, 8 that the geometrical form of a crystallized mineral is the external evidence of the internal molecular structure. A full knowledge in regard to this structure, however, can only be obtained by the study of the various physical characters included in the classes enumerated above.

Of these characters, the specific gravity merely gives indication of the atomic mass of the elements present, and further, of the state of molecular aggregation. The first of these points is illustrated by the high specific gravity of compounds of lead; the second, by the distinction observed, for example, between carbon in the form of the diamond, with a specific gravity of 3·5, and the same chemical substance as the mineral graphite, with a specific gravity of only 2.

All the other characters (except the relatively unimportant ones of Class VI) in general vary according to the direction in the crystal; in other words they have a definite orientation. For all of them it is true that *directions which are crystallographically identical have like physical characters.*

In regard to the converse proposition — viz., *that in all directions crystallographically dissimilar there may be a variation in the physical characters*, an important distinction is to be made. This proposition holds true for all crystals, so far as the characters of Class I are concerned; that is, those depending upon the cohesion and elasticity, as shown in the cleavage, hardness, the planes of molecular gliding, the etching-figures, etc. It is also true in the case of pyro-electricity and piezo-electricity.

It does *not* apply in the same way with respect to the characters which involve the propagation of light (and radiant heat), the change of volume with change of temperature; further, electric radiation, magnetic induction, etc.

Thus, although it will be shown that the optical characters of crystals are in agreement in general with the symmetry of their form, they do not show all the variations in this symmetry. It is true, for example, that all directions are optically similar in a crystal belonging to any class under the isometric system; but this is obviously not true of its molecular cohesion, as may be shown by the cleavage. Again, all directions in a tetragonal crystal at right angles to the vertical axis are optically similar; but this again is not true of the cohesion. These points are further elucidated under the description of the special characters of each group.

I. CHARACTERS DEPENDING UPON COHESION AND ELASTICITY

276. Cohesion, Elasticity. — The name *cohesion* is given to the force of attraction existing between the molecules of one and the same body, in consequence of which they offer resistance to any influence tending to separate them, as in the breaking of a solid body or the scratching of its surface.

Elasticity is the force which tends to restore the molecules of a body back into their original position, from which they have been disturbed, as when a body has suffered change of shape or of volume under pressure.

The varying degrees of cohesion and elasticity for crystals of different minerals, or for different directions in the same crystal, are shown in the prominent characters: cleavage, fracture, tenacity, hardness; also in the gliding-planes, percussion-figures or pressure-figures, and the etching-figures.

277. Cleavage. — Cleavage is the tendency of a crystallized mineral to break in certain definite directions, yielding more or less smooth surfaces. It obviously indicates a minimum value of cohesion in the direction of easy fracture — that is, normal to the cleavage-plane itself. The cleavage parallel to the cubic faces of a crystal of galena is a familiar illustration. An amorphous body (p. 8) necessarily can show no cleavage.

As stated in Art. **31**, the consideration of the molecular structure of crystals shows that a cleavage-plane must be a direction in which the molecules are closely aggregated together; while normal to this the distance between successive layers of molecules must be relatively large, and hence this last is the direction of easy separation. It further follows that cleavage can exist only parallel to some possible face of a crystal, and, further, that this must be one of the common fundamental forms. Hence in cases where the choice in the position of the axes is more or less arbitrary the presence of cleavage is properly regarded as showing which planes should be made fundamental. Still again, cleavage is the same in all directions in a crystal which are crystallographically identical.

Cleavage is defined, (1) according to its direction, as cubic, octahedral, rhomobohedral, basal, prismatic, etc. Also, (2) according to the ease with which it is obtained, and the smoothness of the surface yielded. It is said to be *perfect* or *eminent* when it is obtained with great ease, affording smooth, lustrous surfaces, as in mica, topaz, calcite. Inferior degrees of cleavage are spoken of as distinct, indistinct or imperfect, interrupted, in traces, difficult. These terms are sufficiently intelligible without further explanation. It may be noticed that the cleavage of a species is sometimes better developed in some of its varieties than in others.

278. Cleavage in the Different Systems. — (1) In the ISOMETRIC SYSTEM, cleavage is *cubic*, when parallel to the faces of the cube; this is the common case, as illustrated by galena and halite. It is also often *octahedral* — that is, parallel to the octahedral faces, as with fluorite and the diamond. Less frequently it is *dodecahedral*, or parallel to the faces of the rhombic dodecahedron, as with sphalerite.

In the TETRAGONAL SYSTEM, cleavage is often *basal*, or parallel to the basal plane, as with apophyllite; also *prismatic*, or parallel to one (or both) of the square prisms, as with rutile and wernerite; less frequently it is *pyramidal*, or parallel to the faces of the square pyramid, as with scheelite.

In the HEXAGONAL SYSTEM, cleavage is usually either *basal*, as with beryl, or *prismatic*, parallel to one of the six-sided prisms, as with nephelite; *pyramidal* cleavage, as with pyromorphite, is rare and imperfect.

In the RHOMBOHEDRAL DIVISION, besides the basal and prismatic cleavages, *rhombohedral* cleavage, parallel to the faces of a rhombohedron, is also common, as with calcite and the allied species.

In the ORTHORHOMBIC SYSTEM, cleavage parallel to one or more of the pinacoids is common. Thus it is *basal* with topaz, and in all three pinacoidal directions with anhydrite. *Prismatic* cleavage is also common, as with barite; in this case the arbitrary position assumed in describing the crystal may make this cleavage parallel to a "horizontal prism," or dome.

In the MONOCLINIC SYSTEM, cleavage parallel to the clinopinacoid, is common, as with orthoclase, gypsum, heulandite and euclase; also *basal*, as with the micas and orthoclase, or parallel to the orthopinacoid; also *prismatic*, as with amphibole. Less frequently cleavage is parallel to a hemi-pyramid, as with gypsum.

In the TRICLINIC SYSTEM, it is usual and proper to so select the fundamental form as to make the cleavage directions correspond with the pinacoids.

279. In some cases cleavage which is ordinarily not observed may be developed by a sharp blow or by sudden change of temperature. Thus, quartz is usually conspicuously free from cleavage, but a quartz crystal heated and plunged into cold water often shows planes of separation * parallel to both the + and − rhombohedrons and to the prism as well. Similarly, the prismatic cleavage of pyroxene is observed with great distinctness in thin sections, made by grinding, while not so readily noted in large crystals.

When the cleavage is parallel to a closed form — that is, when it is cubic, octahedral, dodecahedral, or rhombohedral (also pyramidal in the tetragonal, hexagonal, and orthorhombic systems) — solids resembling crystals may often be broken out from a single crystalline individual, and all the fragments have the same angles. It is, in general, easy to distinguish such a cleavage form, as a cleavage octahedron of fluorite, from a true crystal by the splintery character of the faces of the former.

280. Cleavage and Luster. — The face of a crystal parallel to which there is perfect cleavage often shows a pearly luster (see p. 249), due to the partial separation of the crystal into parallel plates. This is illustrated by the basal plane of apophyllite, the clinopinacoid of stilbite and heulandite. An iridescent play of colors is also often seen, as with calcite, when the separation has been sufficient to produce the prismatic colors by interference.

281. Gliding-planes. — Closely related to the cleavage directions in their connection with the cohesion of the molecules of a crystal are the *gliding-planes*, or directions parallel to which a slipping of the molecules may take place under the application of mechanical force, as by pressure.

This may have the result of simply producing a separation into layers in the given direction, or, on the other hand, and more commonly, there may be a revolution of the molecules into a new twinning-position, so that *secondary twinning-lamellæ* are formed.

Thus, if a crystal of halite, or rock salt, be subjected to gradual pressure in the direction of a dodecahedral face, a plane of separation is developed normal to this and hence in the direction of another face of the same form. There are six such directions of molecular slipping and separation in a crystal of this substance. Certain kinds of mica of the biotite class often show pseudo-crystalline faces, which are undoubtedly secondary in origin — that is, have been developed by pressure exerted subsequently to the growth of the crystal (cf. Fig. 489).

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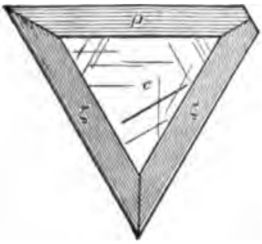
* Lehmann (Zs. Kr., 11, 608, 1886) and Judd (Min. Mag., 8, 7, 1888) regard these as gliding-planes (see Art. 281).

489



Biotite

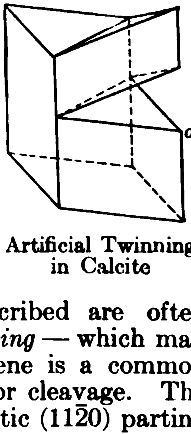
In stibnite, the base, $c(001)$, normal to the plane of perfect cleavage, is a gliding-plane. Thus a slipping of the molecules without their separation may be made to take place by pressure in a plane ($\|c$) normal to the direction of perfect cleavage ($\|b$). A slender prismatic crystal supported near the ends and pressed downward by a dull edge is readily bent, or knicked, in this direction without the parts beyond the support being affected.

282. Secondary Twinning. — The other case mentioned in the preceding article, where molecular slipping is accompanied by a half-revolution (180°) of the molecules into a new twinning-position (see p. 160 *et seq.*), is well illustrated by calcite. Pressure upon a cleavage-fragment may result in the formation of a number of thin lamellæ in twinning-position to the parent mass, the twinning-plane being the obtuse negative rhombohedron, $e(01\bar{1}2)$. Secondary twinning-lamellæ similar to these are often observed in natural cleavage-masses of calcite, and particularly in the grains of a crystalline limestone, as observed in thin sections under the microscope.

Secondary twinning-lamellæ may also be produced (and are often noted in nature) in the case of the triclinic feldspars, pyroxene, barite, etc. A secondary lamellar structure in quartz has been observed by Judd, in which the lamellæ consisted of right-handed and left-handed portions.

By the proper means a complete calcite twin may be artificially produced by pressure. Thus, if a cleavage-fragment of prismatic form, say 6–8 mm. in length and 3–6 mm. in breadth, be placed with the obtuse edge on a firm horizontal support, and pressed by the blade of an ordinary tableknife on the other obtuse edge (at *a*, Fig. 490), the result is that a portion of the crystal is reversed in position, as if twinned parallel to the plane $(01\bar{1}2)$ which in the figure lies in a vertical position. If skillfully done, the twinning surface is perfectly smooth, and the re-entrant angle corresponds exactly with that required by theory.

490



Artificial Twinning in Calcite

283. Parting. — The secondary twinning-planes described are often directions of an easy separation — conveniently called *parting* — which may be mistaken for cleavage.* The basal parting of pyroxene is a common example of such pseudo-cleavage; it was long mistaken for cleavage. The basal and rhombohedral $(10\bar{1}1)$ and the less distinct prismatic $(11\bar{2}0)$ parting of corundum; the octahedral parting of magnetite (cf. Fig. 474, p. 176), are other examples.

An important distinction between cleavage and parting is this: parting can exist only in certain definite planes — that is, on the surface of a twinning-lamella — while the cleavage may take place in *any* plane having the given direction.

284. Percussion-figures. — Immediately connected with the gliding-planes are the figures — called *percussion-figures* † — produced upon a crystal section by a blow or pressure with a suitable point. In such cases, the method described serves to develop more or less well-defined cracks whose orientation varies with the crystallographic direction of the surface. Thus upon the cubic face of a crystal of halite a four-rayed, star-shaped figure is produced with arms parallel to the diagonals — that is, parallel to the dodecahedral faces. On an octahedral face a three-rayed star is obtained.

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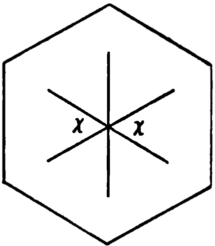
* The lamellar structure of a massive mineral, without twinning, may also be the cause of a fracture which can be mistaken for cleavage.

† The percussion-figures are best obtained if the crystal plate under investigation be supported upon a hard cushion and a blow be struck with a light hammer upon a steel rod the slightly rounded point of which is held firmly against the surface.

The percussion-figures in the case of the micas have been often investigated, and, as remarked later, they form a means of fixing the true orientation of a cleavage-plate having no crystalline outlines. The figure (Fig. 491) is here a six-rayed star one of whose branches is parallel to the clinopinacoid (*b*), the others approximately parallel to the intersection edges of the prism (*m*) and base (*c*).*

491



Pressure upon a mica plate produces a less distinct six-rayed star, diagonal to that just named; this is called a *pressure-figure.*

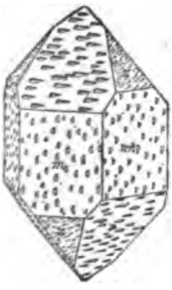
285. Solution-planes. — In the case of many crystals, it is possible to prove the existence of certain directions, or structure-planes, in which chemical action takes place most readily — for example, when a crystal is under great pressure. These directions of chemical weakness have been called *solution-planes.* They often manifest themselves by the presence of a multitude of oriented cavities of crystalline outline (so-called negative crystals) in the given direction.

These solution-planes in certain cases, as shown by Judd, are the same as the directions of secondary lamellar twinning, as is illustrated by calcite. Connected with this is the *schillerization* (see Art. 369), observed in certain minerals in rocks (as diallage, schillerspar).

286. Etching-figures. — Intimately connected with the general subjects here considered, of cohesion in relation to crystals, are the figures produced by etching on crystalline faces; these are often called *etching-figures.* This method of investigation, developed particularly by Baumhauer, is of high importance as revealing the molecular structure of the crystal faces under examination, and therefore the symmetry of the crystal itself.

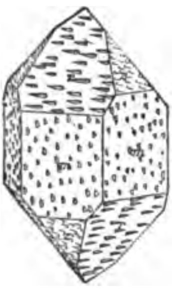
The etching is performed mostly by solvents, as by water in some cases, more generally the ordinary mineral acids, or caustic alkalies, also by steam at a high pressure and hydrofluoric acid; the last is especially powerful in its action, and is used frequently with the silicates. The figures produced are in the majority of cases angular depressions, such as low triangular or quadrilateral pyramids, whose outlines may run parallel to some of the crystalline edges. In some cases the planes produced can be referred to occurring crystallographic faces. They appear alike on similar faces of crystals, and hence serve to distinguish different forms, perhaps in appearance identical, as the two sets of faces in the ordinary double pyramid of quartz; so, too, they reveal the compound twinning-structure common on some crystals, as quartz and aragonite.

492



Quartz, right-handed crystal

493



Quartz, left-handed crystal

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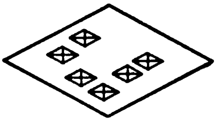
* Cf. Walker, Am. J. Sc., 2, 5, 1896, and G. Friedel, Bull. Soc. Min., 19, 18, 1896. Walker found the angle opposite *b*(010) (χ in Fig. 491) to be 53° to 56° for muscovite, 59° for lepidolite, 60° for biotite, and 61° to 63° for phlogopite.

Further, their form in general corresponds to the symmetry of the group to which the given crystal belongs. They thus reveal the trapezohedral symmetry of quartz and the difference between a right-handed and left-handed crystal (Figs. 492, 493); the distinction between calcite and dolomite (Figs. 496, 497); the distinctive character of apatite, pyromorphite, etc.; the hemimorphic symmetry of calamine and nephelite (cf. Fig. 237, p. 102), etc.; they also prove by their form the monoclinic crystallization of muscovite and other micas (Fig. 495).

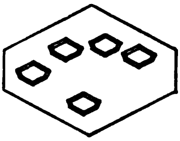
Fig. 494 shows the etching-figures formed on a basal plane (cleavage) of topas by fused caustic potash; Fig. 495, those on a cleavage-plate of muscovite by hydrofluoric acid; Fig. 496, upon a rhombohedral face of calcite, and Fig. 497, on one of dolomite by dilute hydrochloric acid.

494



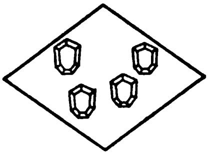
Topas

495



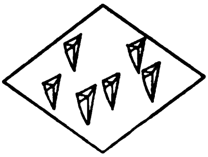
Muscovite

496



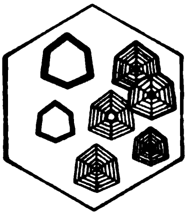
Calcite

497



Dolomite

498



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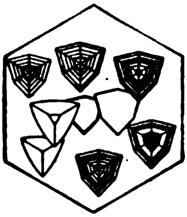
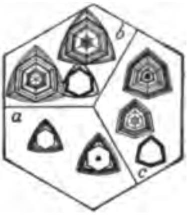


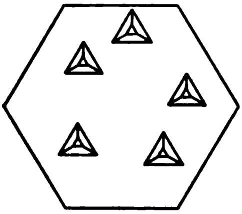
500



Spangolite

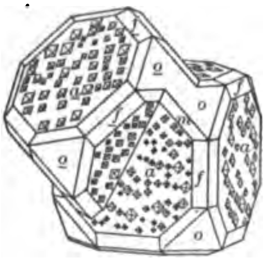
The shape of the etching-figures may vary with the same crystal with the nature of the solvent employed, though their symmetry remains constant. For example, Fig. 498 shows the figures obtained with spangolite by the action of sulphuric acid, Fig. 499 by the same diluted, and Fig. 500 by hydrochloric acid of different degrees of concentration.

501



Corundum

502



Fluorite

Of the same nature as the etching-figures artificially produced, in their relation to the symmetry of the crystal, are the markings often observed on the natural faces of crystals. These are sometimes secondary, caused by a natural etching process, but are more often an irregularity in the crystalline development of the crystal. The inverted triangular depressions often seen on the octahedral faces of diamond crystals are an example. Fig. 501 shows natural depressions, rhombohedral in character, observed on corundum crystals from Montana (Pratt). Fig. 502 shows a twin crystal of fluorite with natural etching-figures (Pirsson);

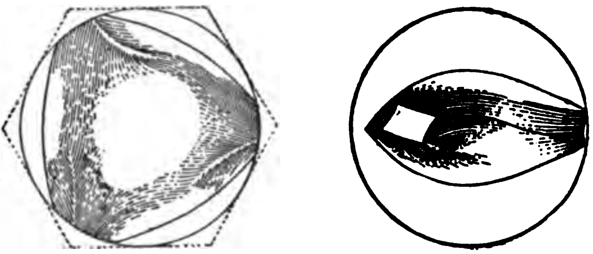
these are minute pyramidal depressions whose sides are parallel to the faces of the trapezohedron (311).

287. Corrosion Forms. — If the etching process spoken of in the preceding article — whether natural or artificial — is continued, the result may be to destroy the original crystalline surface and to substitute for it perhaps a multitude of minute elevations, more or less distinct; or, further, new faces may be developed, the crystallographic position of which can often be determined, though the symbols may be complex. The mere loss of water in some cases produces certain corrosive forms.

Penfield subjected a sphere of quartz (from a simple right-handed individual) to the prolonged action of hydrofluoric acid. It was found that it was attacked rapidly in the direction of the vertical axis, but barely at all at the + extremities of the horizontal axes. Figs. 503, 504 show the form remaining after the sphere had been etched for seven weeks; Fig. 503 is a basal view; Fig. 504, a front view; the circle shows the original form of the sphere, the dotted hexagon the position of the axes.

288. Fracture. — The term *fracture* is used to define the form or kind of surface obtained by breaking in a direction other than that of cleavage in crystallized minerals, and in any direction in massive minerals. When the cleavage is highly perfect in several directions, as the rhombohedral cleavage of calcite, fracture is often not readily obtainable.

503 504



Etched Sphere of Quartz

Fracture is defined as:

(*a*) *Conchoidal;* when a mineral breaks with curved concavities, more or less deep. It is so called from the resemblance of the concavity to the valve of a shell, from concha, *a shell.* This is well illustrated by obsidian, also by flint. If the resulting forms are small, the fracture is said to be *small-conchoidal;* if only partially distinct, it is *subconchoidal.*

(*b*) *Even;* when the surface of fracture, though rough with numerous small elevations and depressions, still approximates to a plane surface.

(*c*) *Uneven;* when the surface is rough and entirely irregular; this is true of most minerals.

(*d*) *Hackly;* when the elevations are sharp or jagged; broken iron.

Other terms also employed are *earthy*, *splintery*, etc.

289. Hardness. — The *hardness* of a mineral is measured by the resistance which a smooth surface offers to abrasion. The degree of hardness is determined by observing the comparative ease or difficulty with which one mineral is scratched by another, or by a file or knife.

In minerals there are all grades of hardness, from that of talc, impressible by the finger-nail, to that of the diamond. To give precision to the use of this character, a *scale of hardness* was introduced by Mohs.* It is as follows:

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* The interval between 2 and 3, and 5 and 6, in the scale of Mohs, being a little greater than between the other numbers, Breithaupt proposed a scale of *twelve* minerals; but the scale of Mohs is now universally accepted.

1. *Talc.*
2. *Gypsum*
3. *Calcite.*
4. *Fluorite.*
5. *Apatite.*
6. *Orthoclase.*
7. *Quartz.*
8. *Topaz.*
9. *Corundum.*
10. *Diamond.*

Crystalline varieties with smooth surfaces should be taken so far as possible.

If the mineral under examination is scratched by the knife-blade as easily as calcite its hardness is said to be 3; if less easily than calcite and more so than fluorite its hardness is 3·5. In the latter case the mineral in question would be scratched by fluorite but would itself scratch calcite. It need hardly be added that great accuracy is not attainable by the above methods, though, indeed, for purposes of the determination of minerals, exactness is quite unnecessary.

It should be noted that minerals of grade 1 have a greasy feel to the hand; those of grade 2 are easily scratched by the finger-nail; those of grade 3 are rather readily cut, as by a knife; of grade 4, scratched rather easily by the knife; grade 5, scratched with some difficulty; grade 6, barely scratched by a knife, but distinctly by a file — moreover, they also scratch ordinary glass. Minerals as hard as quartz (H. = 7), or harder, scratch glass readily but are little touched by a file; the few species belonging here are enumerated in Appendix B; they include all the gems.

290. Sclerometer. — Accurate determinations of the hardness of minerals can be made in various ways, one of the best being by use of an instrument called a *sclerometer*. The mineral is placed on a movable carriage, with the surface to be experimented upon horizontal; this is brought in contact with a steel point (or diamond point), fixed on a support above; the weight is then determined which is just sufficient to move the carriage and produce a scratch on the surface of the mineral.

By means of such an instrument the hardness of the different faces of a given crystal has been determined in a variety of cases. It has been found that different faces of a crystal (*e.g.*, cyanite) differ in hardness, and the same face may differ as it is scratched in different directions. In general, differences in hardness are noted only with crystals which show distinct cleavage; the hardest face is that which is intersected by the plane of most complete cleavage. Further, of a single face, which is intersected by cleavage-planes, the direction perpendicular to the cleavage-direction is the softer, those parallel to it the harder.

This subject has been investigated by Exner (p. 194), who has given the form of the *curves of hardness* for the different faces of many crystals. These curves are obtained as follows: the least weight required to scratch a crystalline surface in different directions, for each 10° or 15°, from 0° to 180°, is determined with the sclerometer; these directions are laid off as radii from a center, and the length of each is made proportional to the weight fixed by experiment — that is, to the hardness thus determined; the line connecting the extremities of these radii is the curve of hardness for the given face.

The following table gives the results obtained * (see literature) in comparing the hardness of the minerals of the scale from corundum, No. 9, taken as 1000, to gypsum, No. 2. Pfaff used the method of boring with a standard point, the hardness being determined by the number of rotations; Rosiwal used a standard powder to grind the surface, Jaggar employed his micro-sclerometer, the method being essentially a modification of that of

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* The numbers are here given as tabulated by Jaggar.

Pfaff. By means of this instrument he is able to test the hardness of the minerals present in a thin section under the microscope. Measurements of absolute hardness have also been made by Auerbach. Holmquist has recently made many hardness tests by the grinding method. His results with regard to the minerals of the scale of hardness agree fairly well with those of Rosiwal given below but show considerable discrepancies with the results obtained by the other methods. He, like Rosiwal, finds that topaz is lower in the scale than quartz.

	Pfaff, 1884	Rosiwal, 1892	Jaggar, 1897
9. Corundum	1000	1000	1000
8. Topaz	459	138	152
7. Quartz	254	149	40
6. Orthoclase	191	28·7	25
5. Apatite	53·5	6·20	1·23
4. Fluorite	37·3	4·70	·75
3. Calcite	15·3	2·68	·26
2. Gypsum	12·03	·34	·04

291. Relation of Hardness to Chemical Composition. — Some general facts of importance can be stated * in regard to the connection between the hardness of a mineral and its chemical composition.

1. Compounds of the heavy metals, as silver, copper, mercury, lead, etc., are *soft*, their hardness seldom exceeding 2·5 to 3.

Among the compounds of the common metals, the sulphides (arsenides) and oxides of iron (also of nickel and cobalt) are relatively *hard* (*e.g.*, for pyrite H. = 6 to 6·5; for hematite H. = 6, etc.); here belong also columbite, iron niobate; tantalite, iron tantalate; wolframite, iron tungstate.

2. The sulphides are mostly relatively soft (except as noted in 1), also most of the carbonates, sulphates, and phosphates.

3. Hydrous salts are relatively soft. This is most distinctly shown among the silicates — *e.g.*, compare the feldspars and zeolites.

4. The conspicuously hard minerals are found chiefly among the oxides and silicates; many of them are compounds containing aluminium — *e.g.*, corundum, diaspore, chrysoberyl, and many alumino-silicates. Outside of these the borate, boracite, is hard (H. = 7); also iridosmine.

On the relation of hardness to specific gravity, see Art. **302.**

292. Practical Suggestions. — Several points should be regarded in the trials of hardness:

(1) If the mineral is slightly altered, as is often the case with corundum, garnet, etc., the surface may be readily scratched when this would be impossible with the mineral itself; a trial with an edge of the latter will often give a correct result in such a case.

(2) A mineral with a granular surface often appears to be scratched when the grains have been only torn apart or crushed.

(3) A relatively soft mineral may leave a faint white ridge on a surface, as of glass, which can be mistaken for a scratch if carelessly observed.

(4) A crystal, as of quartz, is often slightly scratched by the edge of another of the same species and like hardness.

(5) The scratch should be made in such a way as to disfigure the specimen as little as possible.

293. Tenacity. — Minerals may be either brittle, sectile, malleable, or flexible.

(*a*) *Brittle;* when parts of a mineral separate in powder or grains on attempting to cut it, as calcite.

(*b*) *Sectile;* when pieces may be cut off with a knife without falling to powder, but still the mineral pulverizes under a hammer. This character is intermediate between brittle and malleable, as gypsum.

(*c*) *Malleable;* when slices may be cut off, and these slices flattened out under a hammer; native gold, native silver.

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* See further in Appendix B.

(*d*) *Flexible;* when the mineral will bend without breaking, and remain bent after the bending force is removed, as talc.

The tenacity of a substance is properly a consequence of its elasticity.

294. Elasticity. — The elasticity of a solid body expresses at once the resistance which it makes to a change in shape or volume, and also its tendency to return to its original shape when the deforming force ceases to act. If the *limit of elasticity* is not passed, the change in molecular position is proportional to the force acting, and the former shape of volume is exactly resumed; if this limit is exceeded, the deformation becomes permanent, a new position of molecular equilibrium having been assumed; this is shown in the phenomena of gliding-planes and secondary twinning, already discussed. The magnitude of the elasticity of a given substance is measured by the *coefficient of elasticity*, or, better, the coefficient of restitution. This is defined as the relation, for example, between the elongation of a bar of unit section to the force acting to produce this effect; similarly of the bending or twisting of a bar. The subject was early investigated acoustically by Savart; in recent years, Voigt and others have made accurate measures of the elasticity of many substances and of the crystals of the same substance in different directions. The elasticity of an amorphous body is the same in all directions, but it changes in value with change of crystallographic direction in all crystals.

The distinction between *elastic* and *inelastic* is often made between the species of the mica group and allied minerals. Muscovite, for example, is described as "highly elastic," while phlogopite is much less so. In this case it is not true in the physcial sense that muscovite has a high value for the coefficient of elasticity; its peculiarity lies rather in the fact that its elasticity is displayed through unusually wide limits.

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II. SPECIFIC GRAVITY OR RELATIVE DENSITY

295. Definition of Specific Gravity. — The specific gravity of a mineral is the ratio of its density * to that of water at 4° C. (39·2° F.). This relative density may be learned in any case by comparing the ratio of the weight of a certain volume of the given substance to that of an equal volume of water; hence the specific gravity is often defined as: *the weight of the body divided by the weight of an equal volume of water.*

The statement that the specific gravity of graphite is 2, of corundum 4, of galena 7·5, etc., means that the densities of the minerals named are 2, 4, and 7·5, etc., times that of water; in other words, as familiarly expressed, any volume of them, a cubic inch for example, weighs 2 times, 4 times, 7·5 times, etc., as much as a like volume, a cubic inch, of water.

Strictly speaking, since the density of water varies with its expansion or contraction under change of temperature, the comparison should be made with water at a fixed temperature, namely 4° C. (39·2° F.), at which it has its maximum density. If made at a higher temperature, a suitable correction should be introduced by calculation. Practically, however, since a high degree of accuracy is not often called for, and, indeed, in many cases is impracticable to attain in consequence of the nature of the material at hand, in the ordinary work of obtaining the specific gravity of minerals the temperature at which the observation is made can safely be neglected. Common variations of temperature would seldom affect the value of the specific gravity to the extent of one unit in the third decimal place.

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* The *density* of a body is strictly *the mass of the unit volume.* Thus if a cubic centimeter of water (at its maximum density, 4° C. or 39·2° F.) is taken as the unit of mass, the density of any body — as gold — is given by the number of grams of mass (about 19) in a cubic centimeter; in this case the same number, 19, gives the relative density or specific gravity. If, however, a pound is taken as the unit of mass, and the cubic foot as the unit of volume, the mass of a cubic foot of water is 62·5 lbs., that of gold about 1188 lbs., and the specific gravity is the ratio of the second to the first, or, again, 19.

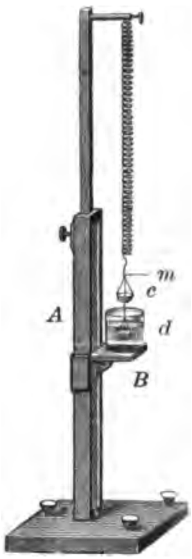
For the same reason, it is not necessary to take into consideration the fact that the observed weight of a fragment of a mineral is less than its true weight by the weight of air displaced.

Where the nature of the investigation calls for an *accurate* determination of the specific gravity (*e.g.*, to four decimal places), no one of the precautions in regard to the purity of material, exactness of weight-measurement, temperature, etc., can be neglected.* The accurate values spoken of are needed in the consideration of such problems as the specific volume, the relation of molecular volume to specific gravity, and many others.

296. Determination of the Specific Gravity by the Balance. — The direct comparison by weight of a certain volume of the given mineral with an equal volume of water is not often practicable. By making use, however, of a familiar principle in hydrostatics, viz., that a solid immersed in water, in consequence of the buoyancy of the latter, loses in weight an amount which is equal to the weight of an equal volume of the water (that is, the volume it displaces) — the determination of the specific gravity becomes a very simple process.

The weight of the solid in the air (w) is first determined in the usual manner; then the weight in water is found (w'); the difference between these weights — that is, the loss by immersion ($w - w'$) — is the weight of a volume of water equal to that of the solid; finally, the quotient of the first weight (w) by that of the equal volume of water as determined ($w - w'$) is the specific gravity (G).

505



Spring or Jolly Balance for Specific Gravity

Hence,

$$G = \frac{w}{w - w'}.$$

A common method of obtaining the specific gravity of a firm fragment of a mineral is as follows: First weigh the specimen accurately on a good chemical balance. Then suspend it from one pan of the balance by a horsehair, silk thread, or, better still, by a fine platinum wire, in a glass of water conveniently placed beneath, and take the weight again with the same care; then use the results as above directed. The platinum wire may be wound around the specimen, or where the latter is small it may be made at one end into a little spiral support.

297. The Jolly Balance. — Instead of using an ordinary balance and determining the actual weight, the spiral balance of Jolly, shown in Fig. 505, may be conveniently employed; this is also suitable when the mineral is in the form of small grains. The instrument consists of a spiral spring at the lower end of which are suspended two pans or wire baskets, *c* and *d*, Fig. 505. Upon the movable stand B rests a beaker filled with water. When in adjustment for reading this stand has such a position that the pan *d* is immersed in the water while *c* hangs above it. Upon the upright A there is a mirror upon which is marked a scale. The position of the balance at any time is obtained by so placing the eye that the bead, *m*, and its reflection in the mirror coincide and then reading the position of the top of the bead upon the scale. The first step in the operation consists in getting the position of the spring alone, having the pan *d* immersed in the water in the beaker. Let this reading be represented by *n*. The mineral whose specific gravity is to be determined is then placed on the pan or basket, *c*, and the platform B raised until *d* is properly immersed in the water. The position of the bead *m* is again read. Let this value be represented by N_1. If from N_1 be subtracted the number *n*, expressing the amount to which the scale is stretched by the weight of spring and pans alone, the difference will be proportional to the weight of the mineral. Next, the mineral is placed in the lower pan, *d*, immersed in the water, and again the corresponding scale number, N_2, read. The difference between these readings $(N_1 - N_2)$ is a number proportional to the loss of weight in water. The specific gravity is then

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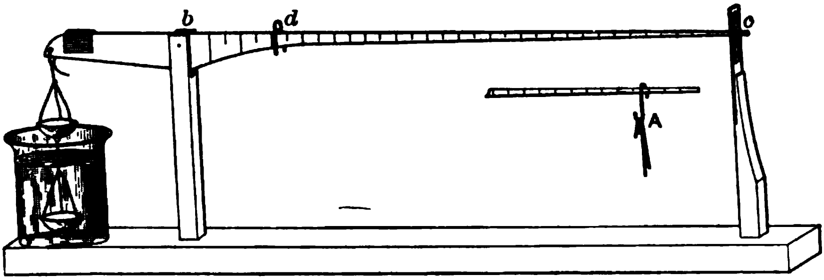
* Cf. Earl of Berkeley in Min. Mag., 11, 64, 1895.

$$G = \frac{N_1 - n}{N_1 - N_2}.$$

It is obviously necessary to have the wires supporting the lower pan immersed to the same depth in the case of each of the three determinations. If care is taken the specific gravity can be obtained accurately to two decimal places.

298. The Beam Balance. — A beam balance described by Penfield is another very simple and quite accurate device for measuring the specific gravity. It is illustrated in Fig. 506, which will make clear its essential parts. The beam is so balanced by a weight on its shorter end that it is very nearly in equilibrium when the lower pan is immersed in water. An exact balance is then obtained by the small rider *d*. When the beam is once balanced this rider is kept stationary and its position disregarded in the subsequent readings. The mineral is first placed in the upper pan and the beam balanced by another rider of such a weight that its position will be near the outer end of the beam.

506



Beam Balance for Specific Gravity, ⅙th Natural Size (after Penfield)

The position of this rider is then read from the scale engraved upon the beam. Let this value be equal to N_1. The mineral is next transferred to the lower pan and the beam again brought into balance by moving this same rider back. The second reading may be represented by N_2. The formula for obtaining the specific gravity is now:

$$G = \frac{N_1}{N\cdot - N_2}.$$

299. Pycnometer. — If the mineral is in the form of grains or small fragments, the specific gravity may be obtained by use of the *pycnometer*.

This is a small bottle (Fig. 507) having a stopper which fits tightly and ends in a tube with a very fine opening. The bottle is filled with distilled water, the stopper inserted, and the overflowing water carefully removed with a soft cloth and then weighed. The weight of the water is obviously the difference between this last weight and that of the bottle and mineral together, as first determined. The mineral whose density is to be determined is also weighed. Lastly the bottle is weighed with the mineral in it and filled with water as described above.* The weight of the water displaced by the mineral is obviously the difference between this last weight and that of the bottle filled with water plus the weight of the mineral. The specific gravity of the mineral is equal to its weight alone divided by the weight of the equal volume of water thus determined. Where this method is followed with sufficient care, especially avoiding any change of temperature in the water, the results may be highly accurate.

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Pycnometer

If the mineral forms a porous mass, it may be first reduced to powder, but it is to be noted that it has been shown by Rose that chemical precipitates have uniformly a higher density than belongs to the same substance in a less finely divided state. This increase of density also characterizes, though to a less extent, a mineral in a fine state of mechanical subdivision. It is explained by the condensation of the water on the surface of the powder.

300. Use of Liquids of High Density. — It is often found convenient both in the determination of the specific gravity and in the mechanical separation of fragments of different specific gravities (*e.g.*, to obtain pure material for analysis, or again in the study of rocks) to use a liquid of high density — that is, a so-called *heavy solution*. One of these is the solution of mercuric iodide in potassium iodide, called the Sonstadt or Thoulet solution. When made with care it has a maximum density of nearly 3·2, which by dilution may be lowered at will.

A second solution, often employed, is the *Klein solution*, the borotungstate of cadmium, having a maximum density of 3·6. This again may be lowered at will by dilution, observing certain necessary precautions. Still a third solution of much practical value is that proposed by Brauns, methylene iodide, which has a specific gravity of 3·324. A number of other solutions, more or less practical, have also been suggested.† When one of these liquids is to be used for the determination of the specific gravity of fragments of a certain mineral it must be diluted until the fragments just float and the specific gravity then obtained, most conveniently by the Westphal balance (Art. **301**).

When, on the other hand, the liquid is to be used for the separation of the fragments of two or more minerals mixed together, the material is first reduced to the proper degree of fineness, the dust and smallest fragments being sifted out, then it is introduced into the solution and this diluted until one constituent after another sinks and is removed. For the convenient application of this method a suitable tube is called for and certain precautions must be observed; compare the papers noted in the literature (p. 200), especially one by Penfield.

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* Care should be taken to prevent air-bubbles being included among the mineral particles. This may be accomplished by placing the bottle under an air-pump and exhausting the air or by suspending the bottle for a short time in a beaker filled with boiling water and then allowing it to cool again before weighing.

† Johannsen, Manual of Petrographic Methods, p. 519 *et seq.*, gives in detail an account of the various solutions, the methods of their preparation, etc.

301. Westphal's Balance. — The Westphal balance is conveniently used to determine the specific gravity of a liquid, and hence of a mineral when a heavy solution is employed (Art. **300**). It consists essentially of a graduated steelyard arm, upon which the weights, in the form of riders, are placed. These must be so adjusted that the sinker is freely suspended in the given liquid while the index at the end points to the zero of the scale and shows that the arm is horizontal (cf. Johannsen, p. 533). The graduation usually allows of the specific gravity being read off directly without calculation.

302. Relation of Density to Hardness, Chemical Composition, etc.— The density, or specific gravity, of a solid depends, first, upon the nature of the chemical substances which it contains, and, second, upon the state of molecular aggregation.

Thus, as an illustration of the first point, all lead compounds have a high density (G. = about 6), since lead is a heavy metal, or, chemically expressed, has a high atomic weight (206·4). Similarly, barium sulphate, barite, has a specific gravity of 4·5, while for calcium sulphate or anhydrite the value is only 2·95 (atomic weight for barium 137, for calcium about 40).

On the other hand, while aluminium is a metal of low density (G. = 2·5 and atomic weight = 27), its oxide, corundum, has a remarkably *high* density (G. = 4) and is also very hard (H. = 9). Again, carbon (atomic weight = 12) has a high density in the diamond (G. = 3·5) and low in graphite (G. = 2); also, the first is hard (H. = 10), the second soft (H. = 1·5). In these and similar cases the high density signifies great molecular aggregation, and hence it is natural that it should be accompanied by great hardness and resistance to the attack of acids.

As bearing upon this point, it is to be noted that the density of many substances is altered by fusion. Again, the same mineral in different states of molecular aggregation may differ (but only slightly) in density. Furthermore, minerals having the same chemical composition have sometimes different densities, corresponding to the different crystalline forms in which they appear. Thus in the case of calcium carbonate ($CaCO_3$), calcite has G. = 2·7, aragonite has G. = 2·9.

303. Average Specific Gravities. — It is to be noted that among minerals of NON-METALLIC LUSTER the *average* specific gravity ranges from 2·6 to 3. Here belong quartz (2·66), calcite (2·7), the feldspars (2·6–2·75), muscovite (2·8). A specific gravity of 2·5 or less is *low*, and is characteristic of soft minerals, and often those which are hydrous (*e.g.*, gypsum, G. = 2·3). The common species fluorite, tourmaline, apatite, vesuvianite, amphibole, pyroxene, and epidote lie just above the limit given, namely, 3·0 to 3·5. A specific gravity of 3·5 or above is relatively *high*, and belongs to hard minerals (as corundum, see Art. **302**), or to those containing a heavy metal, as compounds of strontium, barium, also iron, tungsten, copper, silver, lead, mercury, etc.

With minerals of METALLIC LUSTER, the average is about 5 (here belong pyrite, hematite, etc.), while if below 4 it is relatively low (graphite 2, stibnite 4·5); if 7 or above, relatively high (as galena, 7·5).

Tables of minerals arranged according to their specific gravity are given in Appendix B.

304. Constancy of Specific Gravity. — The specific gravity of a mineral species is a character of fundamental importance, and is highly constant for different specimens of the same species, if pure, free from cavities, solid inclusions, etc., and if essentially constant in composition. In the case of many species, however, a greater or less variation exists in the chemical composition, and this at once causes a variation in specific gravity. The different kinds of garnet illustrate this point; also the various minerals intermediate between the tantalate of iron (and manganese) and the niobate, varying from G. = 7·3 to G. = 5·3.

305. Practical Suggestions. — It should be noted that the determination of the specific gravity has little value unless the fragment taken is pure and is free from impurities, internal and external, and not porous. Care must be taken to exclude air-bubbles, and it will often be found well to moisten the surface of the specimen before inserting it in the water, and sometimes boiling (or the use of the air-pump) is necessary to free it from air. If it absorbs water this latter process must be allowed to go on till the substance is fully saturated. No *accurate* determinations can be made unless the changes of temperature are rigorously excluded and the actual temperature noted.

In a mechanical mixture of two constituents in known proportions, when the specific gravity of the whole and of one are known, that of the other can be readily obtained. This method is often important in the study of rocks.

It is to be noted that the hand may be soon trained to detect a difference of specific gravity, if like volumes are taken, even in a small fragment — thus the difference between calcite or albite and barite, even the difference between a small diamond and a quartz crystal, can be detected.

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III. CHARACTERS DEPENDING UPON LIGHT

GENERAL PRINCIPLES OF OPTICS

306. Before considering the optical characters of minerals in general, and more particularly those that belong to the crystals of the different systems, it is desirable to review briefly some of the more important principles of optics upon which the phenomena in question depend.

For a fuller discussion of the optics of crystals, special reference is made to the works of Groth (translation by Jackson), Liebisch, Mallard, Duparc and Pearce, Rosenbusch (translation by Iddings), Iddings, Johannsen, Winchell, mentioned on p. 3 also to the various advanced text-books of Physics.

307. The Nature of Light. — Light is now considered to be an electromagnetic phenomenon due to a periodic variation in the energy given off by vibrating electrons. This energy is transmitted by a series of periodic changes that show all the characters of ordinary wave phenomena. The light waves, as they are commonly called, possess certain short wave-lengths that are of the correct magnitude to affect the optic nerves. Other similar waves with longer or shorter wave-lengths belong to the same class of phenomena. Immediately beyond the violet end of the visible spectrum come the so-called "ultra-violet" waves with still shorter wave-lengths and on beyond these we have the X-rays and the "gamma" rays produced by radium. Of the waves having greater lengths than those of light waves we have the waves that give rise to the sensation of heat and the Hertzian waves used in wireless. All of these vibrations, while varying enormously in their wave-lengths, belong to the same order of phenomena and obey the same laws. The proportion that the section of the series which produces the effect of light bears to the whole may be strikingly shown when we say that if ordinary white light is broken up into a spectrum a yard long and this then considered to be extended on either end so as to include all known electro-magnetic waves the entire spectrum would be over five million miles in length.

The transmission of light through interstellar space, through liquids and transparent solids, has for some time been explained by the assumption that a medium, called the luminiferous ether, pervades all space, including the intermolecular space of material bodies. In this medium the vibrations of light waves are assumed to take place. For the purposes of the present work, however, it is unnecessary to consider closely the exact nature of light or the mode of its transmission. It will assist greatly, however, in obtaining a clear idea of the behavior of light in crystals if we assume that light waves are mechanical in nature and consist of periodic vibrations in an all-prevailing ether.

308. Wave-motion in General. — A familiar example of wave-motion is given by the series of concentric waves which on a surface of smooth water go out from a center of disturbance, as the point where a pebble has been dropped in. These surface-waves are propagated by a motion of the water-particles which is *transverse* to the direction in which the waves themselves travel; this motion is given from each particle to the next adjoining, and so on. Thus the particles of water at any one spot oscillate up and down,* while the wave moves on as a circular ridge of water of constantly increasing diameter, but of diminishing height. The ridge is followed by a valley, indeed both together properly constitute a wave in the physical sense. This compound wave is followed by another wave and another, until the original impulse has exhausted itself.

Another familiar kind of wave-motion is illustrated by the sound-waves which in the free air travel outward from a sonorous body in the form of concentric spheres. Here the actual motion of the layers of air is forward and back — that is, in the direction of propagation of the sound — and the effect of the transfer of this impulse from one layer to the next is to give rise alternately to a condensed and rarefied shell of air, which together constitute a sound-wave and which expand in spherical waves of constantly decreasing intensity (since the mass of air set in motion continually increases). Sound-waves, as of the voice, may be several feet in length, and they travel at a rate of 1120 feet per second at ordinary temperatures.

309. It is important to understand that in both the cases mentioned, as in every case of free wave-motion, each point on a given wave may be considered as a center of disturbance from which a system of new waves tend to go out. These individual wave-systems ordinarily destroy each other except so far as the onward progression of the wave as a whole is concerned. This is further discussed and illustrated in its application to light-waves (Art **312** and Figs. 509, 510).

In general, therefore, a given wave is to be considered as the resultant of all these minor wave-systems. If, however, a wave encounters an obstacle in its path, as a narrow opening (*i.e.*, one narrow in comparison with the length of the wave) or a sharp edge, then the fact just mentioned explains how the waves seem to bend about the obstacles, since new waves start from them as centers. This principle has an important application in the case of light-waves, explaining the phenomena of diffraction (Art. 331).

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* Strictly speaking, the path of each particle approximates closely to a circle.

310. Still another case of wave-motion may be mentioned, since it is particularly helpful in giving a correct apprehension of light-phenomena. If a long rope, attached at one end, be grasped at the other, a quick motion of the hand, up or down, will give rise to a half wave-form — in one case a crest, in the other a trough — which will travel quickly to the other end and be reflected back with a reversal in its position; that is, if it went forward as a hill-like wave, it will return as a trough. If, just as the wave has reached the end, a second like one be started, the two will meet and pass in the middle, but here for a brief interval the rope is sensibly at rest, since it feels two equal and opposite impulses. This will be seen later to be a case of the simple interference of two like waves opposed in phase.

Again, a double motion of the hand, up and down, will produce a complete wave, with crest and trough, as the result, and this again is reflected back as in the simpler case. Still again, if a series of like motions are continued rhythmically and so timed that each wave is an even part of the whole rope, the two systems of equal and opposite waves passing in the two directions will interfere and a system of so-called stationary waves will be the result, the rope seeming to vibrate in segments to and fro about the position of equilibrium.

Finally, if the end of the rope be made to describe a small circle at a rapid, uniform, rhythmical rate, a system of stationary waves will again result, but now the vibrations of the string will be sensibly in circles about the central line. This last case will be seen to roughly indicate the kind of transverse vibrations by which the waves of circularly polarized light are propagated, while the former case represents the vibrations of waves of what is called plane-polarized light.

All these cases of waves obtained with a rope deserve to be carefully considered and studied by experiment, for the sake of the assistance they give to an understanding of the complex phenomena of light-waves.

311. Light-waves. — In the discussion that follows, in order to make the explanations simpler and clearer, light waves have been treated as if they consisted of mechanical disturbances in a material medium called the ether.

The vibrations in the ether caused by the transmission of a light wave take place in directions transverse to the direction of the movement of the wave. These oscillations have the following characters. When an ether particle is set vibrating it moves from its original position with gradually decreasing velocity until the position of its maximum displacement is reached. Then with gradually increasing velocity it returns to its original position and since it is moving without friction it will continue in the same direction on past this point. Its velocity will then again diminish until it has reached a displacement equal but opposite in direction to its first swing, when it will start back on its course and repeat the oscillation. The varying velocity of such an oscillation would be the same as that shown by a particle moving around a circle with uniform speed if the particle was observed in a direction lying in the plane of the circle. Under these conditions the particle would appear to move forward and backward along a straight line with constantly changing velocity. Such a motion is called simple harmonic motion.

The motion of one ether particle is communicated to another and so on, each, in order, falling a little behind in the time of its oscillation. Consequently, while the individual particles move only back and forth in the same line the wave disturbance moves forward. If, at a given instant of time, the positions of successive particles in their oscillations are plotted, a curve, such as shown in Fig. 508, will be formed. Such a curve is known as a harmonic curve. The oscillatory motion of the particles in a light wave is called a *periodic motion* since it repeats itself at regular intervals. The maximum displacement of a particle from its original position of rest is called the *amplitude* of the wave (distance C–D, Fig. 508). The *phase* of a particle at a given instant is its position in the vibration and the direction in which it is moving.

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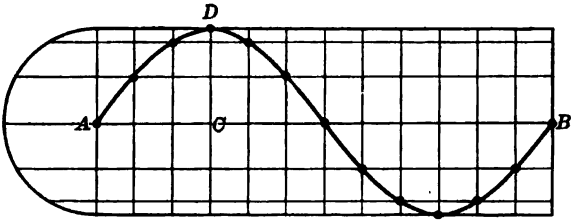

Harmonic Curve

The distance between any particle and the next which is in a like position — *i.e.*, of like *phase*, as A and B — is the *wave-length;* and the time required for this completed movement is the *time* of vibration, or *vibration-period*. The wave-system therefore travels onward the distance of one wave-length in one vibration-period. The intensity of the light varies with the amplitude of the vibration, and the color, as explained in a later article, depends upon the length of the waves; the length of the violet waves is about one-half the length of the red waves.

In *ordinary light* the transverse vibrations are to be thought of as taking place in all planes about the line of propagation. In the above figure, vibrations in one plane only are represented; light that has only one direction of transverse vibration is said to be *plane-polarized*.

Light-waves have a very minute length, only 0·000023 of an inch for the yellow sodium flame, and they travel with enormous velocity, 186,000 miles per second in a vacuum; thus light passes from the sun to the earth in about eight minutes. The vibration-period, or time of one oscillation, is consequently extremely brief; it is given by dividing the distance traveled by light in one second by the number of waves included.*

312. Wave-front. — In an isotropic medium, as air, water, or glass — that is, one in which light would be propagated in all directions about a luminous point with the same velocity — the waves are spherical in form. The *wave-front* is the continuous surface, in this case spherical, which includes all particles that commence their vibration at the same moment of time. Obviously the curvature of the wave-front diminishes as the distance of the source of light increases, and when the light comes from an indefinitely great distance (as the sun) the wave-front becomes sensibly a plane surface. Such waves are usually called *plane waves.* These cases are illustrated by Figs. 509 and 510. In Fig. 509 the luminous point is supposed to be *O*, and the medium being isotropic, it is obvious that the wave-front, as *ABC* . . . *G*, is spherical. It is also made clear by this figure how, as briefly stated in Art. **309**, the resultant of all the individual impulses which go out from the successive points, as *A, B, C*, etc., as centers, form a new wave-front, *abc* . . . *g*, concentric with *ABC* . . . *G*. In Fig. 510 the luminous body is supposed to be at a great distance, so that the wave-front *AB* . . . *F* is a plane surface. Here also the individual impulses from *A*, *B*, etc., unite to form the wave-front *ab* . . . *f* parallel to *AB* . . . *F*.

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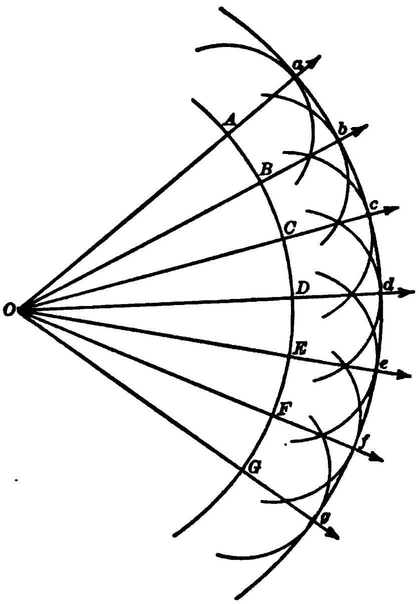
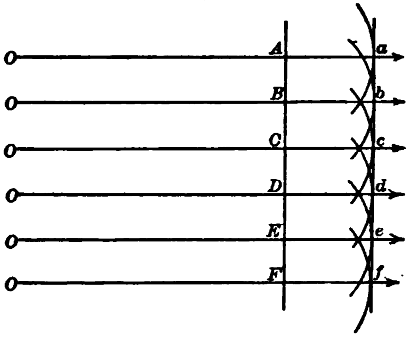
* "On account of the tremendous speed at which light travels the rapidity of vibration, or "frequency" of light as it passes through a fixed point, is extremely great. About eight hundred trillion waves of violet light would pass through such a point in a second. The extreme brevity of the interval of time required for the passage of a single wave of this sort may perhaps be realized better when it is said that one eight-hundred-trillionth of a second is a vastly smaller part of a second than a second is of the whole of historic time." Comstock and Troland, "The Nature of Matter and Electricity," p. 157.

509



313. Light-ray. — The study of light-phenomena is, in certain cases, facilitated by the conception of a *light-ray*, a line drawn from the luminous point to the wave-front, and whose direction is taken so as to represent that of the wave itself.

510



In Fig. 509 *OA*, *OB*, etc., are diverging light-rays, and in Fig. 510 *OA*, *OB*, etc., are parallel light-rays. In both these cases, where the medium is assumed to be isotropic, the light-ray is normal to the wave-front. This is equivalent to saying that the light-wave moves onward in a direction normal to the wave-front.

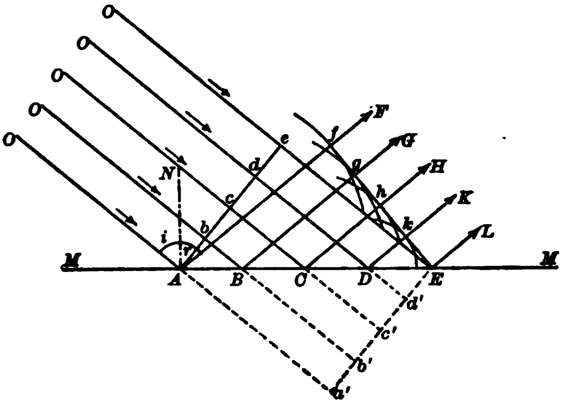
It must be understood that the "light-ray" has no real existence and is to be taken only as a convenient method of representing the direction of motion of the light-waves under varying conditions. Thus when by appropriate means (*e.g.*, the use of lenses) the curvature of the wave-front is altered — for example, if from being a plane surface it is made sharply convex — then the light-rays, at first parallel, are said to be made to diverge. Again, if the convex wave-front is made plane, the diverging light-rays are then said to be made parallel.

314. Wave-length. Color. White Light. — Notwithstanding the very small length of the waves of light, they can be measured with great precision. The visual part of the waves going out from a brilliantly incandescent body, as the glowing carbons of an electric arc-light, may be shown to consist of waves of widely varying lengths. They include red waves whose length is 0·0007604 mm. $\left(\text{about } \frac{1}{39,000} \text{ of an inch}\right)$ and waves whose length constantly diminishes without break, through the orange, yellow, green, and blue to the violet, whose minimum length (0·0003968 mm.) is about half of that of the red. The color of light is commonly said to depend upon its wave-length and will be so spoken of here. This is not strictly true, however, because, since the velocity of light varies with the medium through which it is traveling while the vibration period remains constant under all conditions, it follows that the wave-length of light of the same color must be different in different media. It is, therefore, rather the frequency with which the light waves reach the eye that determines the color sensation. Commonly a given color is produced by the combination of several different wave-lengths of light. It is strictly *monochromatic* only when it corresponds to one definite wave-length; this is nearly true of the bright-yellow sodium line, though strictly speaking this consists of two sets of waves of slightly different lengths.

The effect of "*white light*" is obtained if all the waves from the red to the violet come together to the eye simultaneously; for this reason a piece of platinum at a temperature of 1500° C. appears "white hot."

The radiation from the sources named, either the sun, the electric carbons, or the glowing platinum, includes also longer waves which do not affect the eye, but which, like the light-waves, produce the effect of sensible heat when received upon an absorbing surface, as one of lampblack. There are also, particularly in the radiation from the sun, waves shorter than the violet which also do not affect the eye. The former are called *infra-red*, the latter *ultra-violet* waves.

511



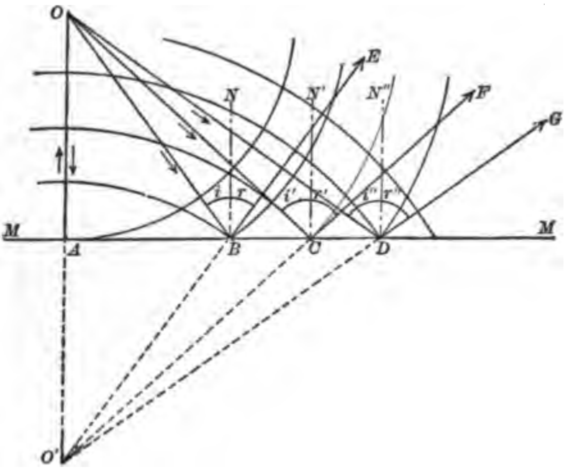
The *brightness* of light depends upon the amplitude of its vibrations and varies directly as the square of this distance.

315. Complementary Colors. — The sensation of white light mentioned above is also obtained when to a given color — that is, light-waves of given wave-length — is combined a certain other so-called *complementary* color. Thus certain shades of pink and green combined, as by the rapid rotation of a card on which the colors form segments, produce the effect of white. Blue and yellow of certain shades are also complementary. For every shade of color in the spectrum there is another one complementary to it in the sense here defined. The most perfect illustration of complementary colors is given by the examination of sections of crystals in polarized light, as later explained.

316. Reflection. — When light-waves come to the boundary which separates one medium from another, as a surface of water, or glass in air, they are, in general, in part *reflected* or returned back into the first medium.

The reflection of light-waves is illustrated by Figs. 511 and 512. In Fig. 511, *M M* is the reflecting surface — here a plane surface — and the light-waves have a plane wave-front (*Abcde*); in other words, the light-rays (*OA*, *Ob*, etc.) are parallel. It is obvious that the wave-front meets the surface first at *A* and successively from point to point to *E*. These points are to be regarded as the centers of new wave-systems which unimpeded would be propagated outward in all directions and at a given instant would have traveled through distances equal to the lines *Aa′*, *Bb′*, etc. Hence the common tangent *fghkE* to the circular arcs drawn with these radii from *A*, *B*, etc., represents the direction of the new or reflected wave-front. But geometrically the angle *eAE* is equal to *fEA*, or the *incident and reflected wave-fronts make equal angles with the reflecting surface.* If *NA* is a normal at *A*, the angle *OAN* — called the *angle of incidence* — is equal to *NAF*, the *angle of reflection.* Hence the familiar law:

512



The angle of incidence is equal to the angle of reflection.

Furthermore, the "incident and reflected rays" both lie in the same plane with the normal to the reflecting surface.

In Fig. 512, where the luminous point is at *O*, the waves going out from it will meet the plane mirror *MM* first at the point *A* and successively at points, as *B*, *C*, *D*, etc., farther away to the right (and left) of *A*. Here also it is easy to show that all the new impulses, which have their centers at *A*, *B*, *C*, etc., must together give rise to a series of reflected waves whose center is at *O'*, at a distance equally great from *MM* measured on a normal to the surface ($OA = O'A$).

Now the lines *OA*, *OB*, etc., which are perpendicular to the wave-front, represent certain incident light-rays, and the eye placed in the direction *BE*, *CF*, etc., will see the luminous point as if at *O'*. It follows from the construction of the figure and can be proved by experiment that if *BN*, *CN'*, etc., are normals to the mirror the angles of incidence, *OBN*, *OCN'*, etc., are equal to the angles of reflection, *NBE*, *N'CF*, etc., respectively. Hence the above law applies to this case also.

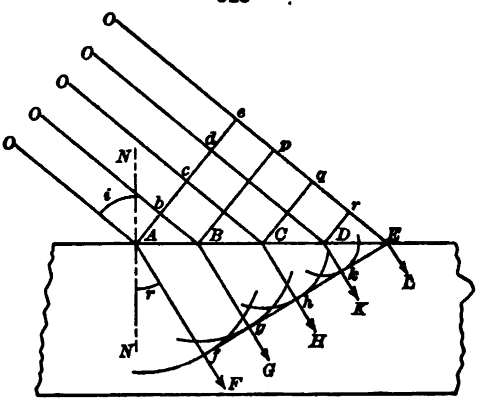
If the reflecting surface is not plane, but, for example, a concave surface, as that of a spherical or parabolic mirror, there is a change in the curvature of the wave-front after reflection, but the same law still holds true.

The proportion of the reflected to the incident light increases with the smoothness of the surface and also as the angle of incidence diminishes. The intensity of the reflected light is a maximum for a given surface in the case of perpendicular incidence (*OA*, Fig. 512).

If the surface is not perfectly polished, *diffuse reflection* will take place, and there will be no distinct reflected ray. It is the diffusely reflected light which makes the reflected surface visible; if the surface of a mirror were *absolutely smooth* the eye would see the reflected body in it only, not the surface itself. Optically expressed, the surface is to be considered smooth if the distance between the scratches upon it is considerably less (say one-fourth) than the wave-length of light.

317. Refraction. — When light passes from one medium into another there is, in general, an increase or decrease in its velocity, and this commonly results in the phenomenon of *refraction* — that is, a change in the direction of propagation. The principles applicable here can be most easily shown in the case of light-waves with a plane wave-front, as shown in Fig. 513 — that is, where the light-rays OA, OB, etc., are parallel. Suppose, for example, that a light-wave, part of whose wave-front is $Abcde$, passes from air obliquely into glass, in which its velocity is about two-thirds as great as it was in the air and suppose the surface of the glass to be plane. At the moment that the ray O–A enters the glass the ray O–E has reached the point e. During the time that the latter ray travels from e to E, the ray O–A will have advanced in the glass a distance equal to $\frac{2}{3}e$–E, or to some point on an arc having this distance as a radius (A–f). In the same way during the time ray O–E passes from the point p to E, ray O–B will have traveled in the glass the distance B–g, equal to $\frac{2}{3}$ p–E. In this way arcs may be drawn about each one of the points A, B, C, etc., and the position of the new wave-front in the glass determined by their common tangent, $Ekhgf$. It is seen that there is a change of direction in the wave-front, or otherwise stated, in the light-ray, the magnitude of which depends on the ratio between the light-velocities in the two media, and, as discussed later, also upon the wave-length of the light. The light-ray is here said to be broken or *refracted*, and for a medium like glass, optically denser than air (*i.e.*, with a lower value of the light-velocity), the refraction is toward the perpendicular with the angle of refraction, r, smaller than the angle of incidence, i. In the opposite case — when light passes into an optically rarer medium — the refraction is away from the perpendicular and the angle of refraction is larger than that of incidence (Art. **323**).

513



318. Refractive Index. — It is obvious from the figure that whatever the direction of the wave-front — that is, of the light-rays — relatively to the given surface, the *ratio* of eE to Af, which determines the direction of the new wave-front (*i.e.*, the direction of a refracted ray, AF) is constant. This ratio is equal to $\frac{V}{v}$ where V is the value of the light-velocity for the first medium (here air) and v for the second (as glass). This constant ratio is commonly represented by n and is known as the *index of refraction*. Therefore

$$n = \frac{eE}{Af}$$

In Fig. 513, by construction,

$$\angle\, eAE = \angle\, i \quad \text{and} \quad \angle\, AEf = \angle\, r.$$

Also,

$$\frac{eE}{AE} = \sin i \quad \text{and} \quad \frac{Af}{AE} = \sin r.$$

Therefore,

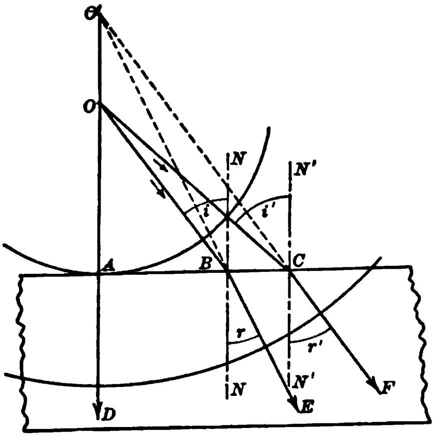
$$\frac{\sin i}{\sin r} = \frac{\dfrac{eE}{AE}}{\dfrac{Af}{AE}} = \frac{eE}{Af} = n.$$

The law of refraction then is given by the expression, $n = \frac{\sin i}{\sin r}$, or may be formulated as follows:

The sine of the angle of incidence bears a constant ratio to the sine of the angle of refraction.

In the case of light passing from air into crown glass this ratio is found to be, $\frac{\sin i}{\sin r} = 1·608$, and this number consequently gives the value of the refractive index, or n, for this kind of glass.

514



The above relation holds true for any wave-system of given wave-length in passing from one medium into another, whatever the wave-front or shape of the bounding surface. In Fig. 514 the luminous point is at O, and it can be readily shown that the new wave-front propagated in the second medium (of greater optical density) has a flattened curvature and corresponding to this a center at O' $\left(\text{where } \frac{O'A}{OA} = \frac{V}{v}\right)$. Here the incident rays OB, OC, are refracted at B and C, the corresponding refracted rays being BE and CF. For this case also the relation holds good,

$$n = \frac{\sin i}{\sin r} = \frac{\sin i'}{\sin r'}, \text{ etc.}$$

If the bounding surface is not plane but curved, as in lenses, there is a change in the curvature of the wave-front in the second medium, but the simple law, $n = \frac{\sin i}{\sin r}$, holds true here also, so long as the medium is isotropic.

The relation between wave-length and refractive index is spoken of in Art. 328.

319. Relation of Refractive Index to Light-velocity. — The discussion of the preceding article shows that if n is the refractive index of a given substance for waves of a certain length, referred to air, V the velocity in air and v the velocity in the given medium, then

$$n = \frac{V}{v}.$$

For two media whose indices are n_1 and n_2 respectively, it consequently follows that

$$\frac{n_1}{n_2} = \frac{v_2}{v_1}.$$

Therefore, *The indices of refraction of two given media for a certain wave-length are inversely proportional to their relative light-velocities.*

In other words, if the velocity of light in air is taken as equal to 1 and the velocity of the same light is found to be one half as great when passing through a given substance, the index of refraction, or n, of that substance when referred to air ($n = 1{\cdot}0$) will be equal to 2·0.

320. Principal Refractive Indices. — The refractive index has, as stated, a constant value for every substance, referred, as is usual, to air (or it may be to a vacuum). In regard to solid media, it is evident from Art. **318** and will be further explained later that those which are *isotropic*, viz., amorphous substances and crystals of the isometric system, can have but a single value of this index. Crystals of the tetragonal and hexagonal systems have, as later explained, *two* principal refractive indices, ϵ and ω, corresponding to the velocities of light-propagation in certain definite directions in them. Further, all orthorhombic, monoclinic, and triclinic crystals have similarly *three* principal indices, α, β, γ. In the latter cases of so-called anisotropic media, the mean refractive index is taken, namely, as the arithmetical mean $\frac{\epsilon + 2\omega}{3}$ and $\frac{\alpha + \beta + \gamma}{3}$.

321. Effect of Index of Refraction upon Luster, etc. — The luster and general appearance of a transparent substance depend largely upon its refractive index. For instance the peculiar aspect of the mineral cryolite, by means of which it is usually possible to readily identify the substance, is due to its low index of refraction. If cryolite is pulverized and the powder poured into a test tube of water it will disappear and apparently go into solution. It is quite insoluble, however, but becomes invisible in the water because its index of refraction (about 1·34) is near that of water (1·335). The light will travel with practically the same velocity through the cryolite as through the water and consequently suffer little reflection or refraction at the surfaces between the two. On the other hand powdered glass with a higher index of refraction than that of water appears white under the same conditions because of the reflection of light from the surfaces of the particles.

Substances having an unusually high index of refraction have an appearance which it is hard to define, and which is generally spoken of as an *adamantine luster*. This kind of luster may be best comprehended by examining specimens of diamond (n = 2·419) or of cerussite (n = 1·98). They have a flash and quality, sometimes almost a metallic appearance, which is not possessed by minerals of a low refractive index. Compare, for example, specimens of cerussite and fluorite (n = 1·434). The usual index of refraction for minerals may be said to range not far from 1·55, and gives to minerals a luster which has been termed *vitreous*. Quartz, feldspar, and halite show good examples of vitreous luster.

Below is given a list of common minerals arranged according to their indices of refraction. For minerals other than those of the isometric system the average value (as defined in the preceding article) is given here.

Water	1·335	Muscovite	1·582
Fluorite	1·434	Beryl	1·582
Orthoclase	1·523	Calcite	1·601
Gypsum	1·524	Topaz	1·622
Quartz	1·547	Tremolite	1·622

Dolomite	1·626	Anglesite	1·884
Aragonite	1·633	Zircon	1·952
Apatite	1·633	Cerussite	1·986
Barite	1·640	Cassiterite	2·029
Diopside	1·685	Sulphur	2·077
Cyanite	1·723	Sphalerite	2·369
Epidote	1·750	Diamond	2·419
Corundum	1·765	Rutile	2·711
Almandite	1·810	Cuprite	2·849
Malachite	1·880	Cinnabar	2·969

322. Relations between Chemical Composition, Density, and Refractive Index. — That definite relations exist between the chemical composition of a substance, its specific gravity, and its index of refraction, has been conclusively shown in many cases. With the plagioclase feldspar group, for instance, the variation in composition which the different members show is accompanied by a direct variation in density and refractive index. Attempts have been made to express these relations in the form of mathematical statements. The two most satisfactory expressions are the one proposed by Gladstone and Dale,[*] $\frac{n-1}{d}$ = constant, and the one proposed independently by Lorentz [†] and Lorenz,[‡] $\frac{n^2-1}{n^2+2}\cdot\frac{1}{d}$ = constant. In these n is equal to the mean refractive index and d to the density. These were originally proposed for use with gases and solutions and for these bodies have been found to serve about equally well. When attempts are made, however, to apply them to crystalline solids the results are at the best only approximate.[§] This is probably because the formulas do not take into consideration the modifications that the crystal structure must introduce.

323. Total Reflection. Critical Angle. — In regard to the principle stated in Art. **318** and expressed by the equation $n = \frac{\sin i}{\sin r}$, two points are to be noted. First, if the angle $i = 0°$, then $\sin i = 0$, and obviously also $r = 0$; in other words, when the ray of light (as *OA*, Fig. 514) coincides with the perpendicular, no change of direction takes place, the ray proceeds onward (*AD*) into the second medium without deviation, but with a change of velocity.

Again, if the angle $i = 90°$, then $\sin i = 1$, and the equation above becomes $n = \frac{1}{\sin r}$ or $\sin r = \frac{1}{n}$. As n has a fixed value for every substance, it is obvious that there will also be a corresponding value of the angle r for the case mentioned. From the above table it is seen that for water, $\sin r = \frac{1}{1·335}$ and $r = 48° \, 31'$; for crown glass ($n = 1·608$), $\sin r = \frac{1}{1·608}$ and $r = 38° \, 27'$; for diamond, $\sin r = \frac{1}{2·42}$ and $r = 24° \, 25'$.

This fact, that for each substance at a particular value of the angle r the angle i becomes equal to 90°, has an important bearing on the behavior of light when it is passing from an optically denser into an optically rarer medium.

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[*] Phil. Trans., **153**, 317, 1863.

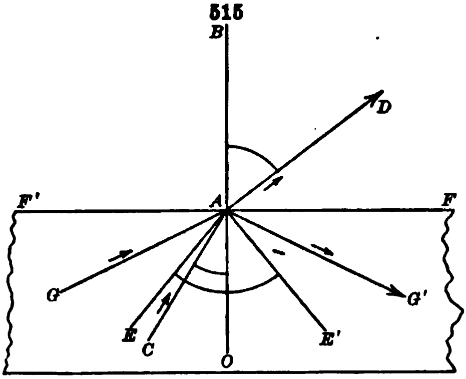
[†] Wiedem. Ann., **9**, 641, 1880.

[‡] Wiedem. Ann., **11**, 70, 1880.

[§] E. S. Larsen, Am. Jour. Sci., **28**, 263, 1909. See also Cheneveau, Ann. Chem. Phys., **12**, 145, 289, 1907.

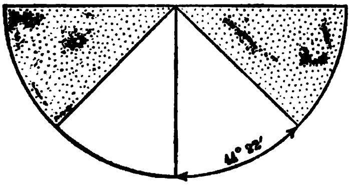
In Fig. 515 we may assume that light rays coming from various directions meet the surface between a block of glass and the air at the point A. Light traveling along the path O–A will pass out into the air without a change in its direction but with an increase in its velocity. If it emerges from the glass at any other angle than 90° the ray on entering the air will be bent away from the perpendicular and the angle of deviation will vary with the angle at which the ray touched the surface and with the index of refraction of the glass. The same law holds true in this case as in the case of a ray entering from the air, except that the formula nows reads $n = \frac{\sin r}{\sin i}$, where r = the angle the ray in air makes with the normal to the surface and i = the angle that the ray makes within the glass to the same normal. In Fig. 515 the ray *C–A* will pass out into the air along the line A–D. But the angle i for the ray E–A = 38° 27′ and, as shown in the preceding paragraph, for glass, where n = 1·608, the angle r in the air will be 90° and the ray will travel along the surface of the glass in the direction A–F. Consequently any ray, such as G–A, which meets the surface of the glass at an angle greater than 38° 27′, will be unable to pass out into the air and will suffer *total reflection* at the surface, passing back into the glass in the direction A–G′, with angle OAG = angle OAG′. The angle at which total reflection takes place for any substance is known as its *critical angle.*

515



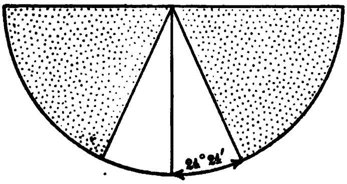
The phenomenon of total reflection is taken advantage of in the cutting of gem stones. According to common practice such a stone is cut with a flat surface on top and with a number of inclined facets on the bottom. The light that enters the stone from above is in a large measure totally reflected from the sloping planes below and comes back to the eye through the stone. The amount of light reflected in this way and the consequent brilliancy of the gem increases with its index of refraction. Two stones cut exactly alike, one from diamond and the other, perhaps, from quartz, would have very different appearances due to this difference in the amount of light totally reflected from their lower facets. This principle is illustrated in Figs. 516 and 517. They

516



Total Reflection in Fluorite $n = 1.43$

517

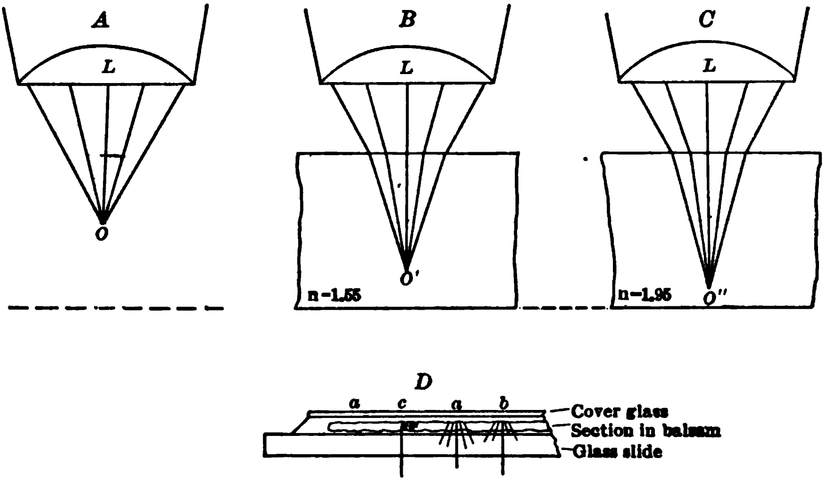


Total Reflection in Diamond $n = 2.42$

represent cross sections of two hemispheres cut, one from fluorite and the other from diamond. It is assumed that light from all directions is focused on the center of the plane surface of each hemisphere. All the light that meets this surface at an angle greater than the critical angle for the mineral will be totally reflected back through the spherical surface. The shaded areas of the figures show the amount of light in each case that would be so reflected and clearly illustrate the optical difference between the two substances.

324. Effect of Index of Refraction upon Microscopic Phenomena. — In the study of minerals, especially in thin sections under the microscope, variations in the index of refraction give effects which are of importance. In Fig. 518 let it be assumed that L is the objective lens of a compound microscope, and that the instrument is exactly focused upon a point O, Fig. 518, A. If now we imagine that a section of some mineral of mean index of refraction is placed under the lens, Fig. 518, B, the point O′ will now be in focus, or as in Fig. 518, C, where the mineral is supposed to have a high index of refraction, the focus will be at O″. Thus it is that with two sections of equal thickness and with the lens in the same position, one looks deeper into the mineral of higher index of refraction. Consequently, when there are two minerals in the same section, the one having a high and the other a low index of refraction (for example, a crystal of zircon, $n = 1.95$, embedded in quartz, $n = 1.55$), the one having the higher index of refraction will apparently have the greater thickness and will appear to stand up in relief above the surface of the mineral of lower index. The apparent relief is furthermore augmented by other properties to be explained below.

518



In preparing thin sections of minerals or rocks for study with the microscope the process, in brief, is to make first a flat surface upon the mineral or rock by grinding it upon a plate supplied with some abrasive. This flat surface is then cemented to a piece of glass by means of Canada balsam and the remainder of the mineral is ground away until only a thin film remains, which in the best rock sections is not over 0·03 mm. in thickness. The section is finally embedded in balsam, n about 1·54, and over it a thin cover glass is laid. In the preparation of a section the surfaces are not polished, hence, from the nature of the abrasive, they must be pitted and scratched and it may be assumed that in cross section such a preparation would be somewhat as represented in Fig. 518, D. When a thin section is examined under the microscope the light enters the section from below, having been reflected up into the microscope tube by an inclined mirror. Before it reaches the section it will have passed through a nicol prism and through a slightly converging lens. Let it be assumed that the mineral at *a*, Fig. 518, D, is one of mean refractive index. The convergent light entering the section will pass with little or no refraction from the mineral into the balsam because their refractive indices are nearly alike. Hence the roughness of the surface of the section is not apparent and the mineral appears as if polished. If there is a crack, as at *b*, so much light penetrates it that it is scarcely visible when the convergent lens is close to the object, but when the latter is lowered, and especially when the light is restricted by the use of an iris diaphragm inserted into the microscope tube, the nearly parallel rays of light will suffer some total reflection along the line of the crack and so make it visible. On the other hand, if the mineral has a high index of refraction there will be innumerable places all over the section where the surfaces are so inclined that the light will suffer total reflection in attempting to pass from the optically dense mineral into the rarer balsam. Hence the uneven surface of the section due to its grinding is plainly visible. This effect is more pronounced if the convergent lens is lowered. The cracks that may exist in a mineral of high index of refraction are for the same reasons much more distinct than in a mineral of low index. Further, if a mineral of high index of refraction is embedded in one of low, *c*, Fig. 518, D, there will be places along its outer edge where total reflection will take place, thus causing its outline to be dark and distinct. This effect combined with the roughened aspect of the surface and the apparent increase in thickness, as described in the preceding paragraph, all tend to make a mineral of high index of refraction stand out conspicuously in relief.

325. Determination of the Indices of Refraction of Mineral Grains under the Microscope. — The considerations of the preceding article suggest a means of determining the indices of refraction of mineral grains under the microscope. If a grain is immersed in a liquid of known index of refraction it is possible to determine whether it has a higher or lower index of refraction than the liquid and by the use of a series of liquids of varying refractive indices it is possible to determine with considerable accuracy the index of refraction of the mineral. A list of liquids * in common use for such purposes, with their indices of refraction is given below.

Mixtures of refined petroleum oils and turpentine............	1·450–1·475
Turpentine and ethylene bromide or clove oil...............	1·480–1·535
Clove oil and α-monobromnaphthalene......................	1·540–1·635
Petroleum oils and α-monobromnaphthalene................	1·475–1·650
α-monobromnaphthalene and methylene iodide.............	1·650–1·740
Sulphur dissolved in methylene iodide.....................	1·740–1·790
Mixtures of methylene iodide with iodides of antimony, arsenic and tin, also sulphur and iodoform (see Merwin)...	1·740–1·870
Methylene iodide and arsenic trisulphide (see Merwin)......	1·740–2·280
Resin-like substances formed from mixtures of piperine and	

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* Wright, Methods of Petrographic-Microscopic Research, p. 98; Merwin, Jour. Wash. Acad. Sc., **3**, 35, 1913.

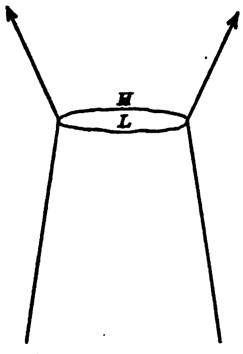
the tri-iodides of arsenic and antimony. These fuse easily and mineral grains can be thus embedded in a thin film of the material.. 1·680–2·100

The indices of refraction of the test liquids can be determined either by the use of the total refractometer or by filling a hollow glass prism with the liquid and using the methods employed with ordinary mineral prisms, see **Art. 327.**

A series of these liquids should be prepared which for most purposes might conveniently show differences in the indices of the different liquids of 0·01. For more exacting work smaller differences between the indices of the members of the series would be of advantage. If these are kept in well stoppered bottles and are protected from the light they will show very little change over considerable periods of time. It is advisable, however, to check their indices at least once a year.

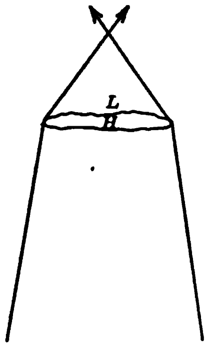
The mineral to be studied should be broken down into uniform small grains (0·05 mm. is usually a good diameter) and then a few grains placed upon a glass slide. A drop of liquid with a known index of refraction is then placed upon the grains and the whole covered with a thin cover glass. When a mineral grain is immersed in a liquid of closely the same index of refraction it loses its sharpness of outline and if the mineral is colorless and the correspondence of the two indices exact it will quite disappear. Certain tests, however, are commonly used to determine the relative indices of the mineral and the liquid which with proper care can distinguish differences as small as 0·01 or with practice and especial care as small as 0·001. To make these tests the condenser below the microscope stage should be lowered and, if the instrument has a sub-stage iris diaphragm, this should be partly closed. Under these conditions the obliquity of the light is reduced and only a small pencil of light composed of nearly parallel rays enters the section. Let Fig. 519 represent a mineral grain illuminated in this way when immersed in a liquid of higher index of refraction. The light rays as they pass from the mineral into the higher refracting liquid above will be bent away from the perpendicular. In the opposite case, Fig. 520, where the mineral has the higher index the reverse will be true and the light rays will be bent toward the perpendicular. This will produce in one case a brighter illumination of the borders of the mineral grain and in the other a brighter illumination of its center. This difference in illumination is, however, commonly so slight as to be certainly detected only with difficulty. The so-called *Becke Test* is commonly used under these circumstances. This consists in focusing upon the grain with a high power objective and then slowly raising or lowering the micro-

519



Grain with Low Refractive Index immersed in Liquid of High Refractive Index

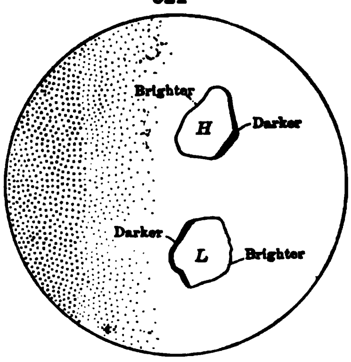
520



Grain with High Refractive Index immersed in Liquid of Low Refractive Index scope tube. In the case illustrated by Fig. 519, when the tube is raised, a narrow line of light will be seen to move outward from the mineral, while when the tube is lowered this line will move inward. In the case illustrated in Fig. 520 the opposite conditions will prevail. A convenient rule to remember is that *when the microscope tube is raised the Becke line will move toward the material of higher refractive index and when the tube is lowered this line will move toward the material of lower index.* This makes a very satisfactory and quite delicate test for distinguishing differences in refractive indices. Sometimes two lines will appear moving in opposite directions and it may be difficult to decide which is the Becke line. This is usually obviated by lowering the condenser or decreasing the aperture in the iris diaphragm. For the use of the Becke test in rock sections, see Art. **326.**

The test upon mineral grains immersed in a liquid may also be made by means of oblique illumination. An oblique pencil of rays may be obtained most conveniently by placing a pencil, a finger, or a piece of cardboard between the reflecting mirror and the polarizer in such a way as to darken one-half of the field of vision. The best results will be obtained by the use of an objective of medium magnifying power. When a mineral grain is viewed under these conditions it will be noted that one of its edges is more brightly illuminated than the other. With the condenser lens lowered and mineral with a lower index of refraction than the liquid, the bright edge of the mineral will be away from the shadow, while if the mineral has a higher index than the liquid the bright edge will be on the side toward the shadow. These conditions are presented in Fig. 521, where *L* and *H* represent grains with indices respectively lower and higher than the liquid in which they are immersed. If the condenser lens is raised effects exactly opposite to those described above will be noted. It is wise, at first at least, to test the apparatus used by observing mineral fragments of known indices and taking note of the effects produced.

521



Commonly the liquids used have a higher dispersion than the mineral to be tested. In other words the liquid will have distinctly different indices of refraction for red and for blue light. If the mineral should have an index intermediate between those for red and blue light in the liquid the grain when illuminated in oblique light will show colored borders. With the condenser lens lowered the edge of the mineral next to the shadow will be colored an orange-red while the edge away from the shadow will be pale blue. If the amount of the dispersion in the liquid (*i.e.*, the difference between the indices for blue and red light) is not too great this effect gives very closely the refractive index of the mineral.

It should be pointed out here that all minerals, except those of the isometric system, show different indices of refraction depending upon the crystal direction in which the light is passing through the mineral. Consequently unorientated grains of a mineral, unless it belongs to the isometric system, will show a variation in the refractive indices depending upon their position on the slide. Sometimes it is possible to determine the crystal orientation of a grain due to some significant cleavage or structure and so obtain the index for some particular crystal direction, but ordinarily all that can be determined is the mean index of refraction of the mineral.

326. The Becke Test in Rock Sections. — The Becke test can be often used in a rock section to determine the relative indices of refraction of two different minerals lying in contact with each other. Their contact plane should be nearly vertical in order to give clear results. The position of this plane can be determined by focusing on the surface of the section and then when the microscope tube is lowered note whether or not the position of the dividing line between the two minerals remains stationary or moves. If it remains stationary or moves only a little, the dividing plane is vertical or nearly so. Under these conditions assume that the cone of light entering from below is focused at point O, Fig. 522, lying on the dividing plane between L (mineral with lower index) and H (mineral with higher index). The light rays 1–6 passing as they do from a mineral of lower index into one of higher will suffer no total reflection and all emerge from the section on the side of H. On the other hand, rays 7–12 attempting to pass from H to L will only in part pass across the dividing plane while the others will be totally reflected and add themselves to rays 1–6 on the side of H. H will therefore show a brighter illumination than L. In this case also when the tube of the microscope is raised the Becke line will be seen moving toward the mineral of higher index or when the tube is lowered toward that of lower index. The best results will be obtained by using an objective of high magnification and the condenser lens must be lowered.

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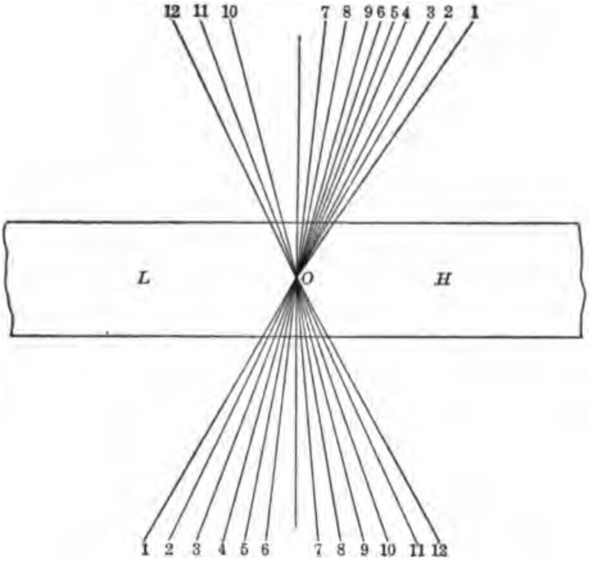

327. Determination of the Index of Refraction by Means of Prisms or Plates. — For the more accurate determination of the indices of refraction of minerals a natural or cut prism or plate of the mineral is used. In all cases, except minerals of the isometric system, the prism or plate used must have a certain crystallographic orientation. This matter, however, will be discussed when the optical characters of such minerals are given. For the present, we will assume that the mineral whose index of refraction is to be determined is isometric in its crystallization. There are two chief methods of determining the index of refraction by the use of a prism.

1. *The Method of Perpendicular Incidence.* — This method, although not

the one most generally employed, is an excellent one to become acquainted with, as it may be used to advantage in some cases and from it the formula necessary for making the calculations is readily derived. It is necessary to have a prism of the mineral which has two plane surfaces meeting at a small angle.

This angle should be small enough so that the light may pass freely through the prism and not suffer any total reflection as it attempts to pass out into the air. For instance with fluorite in which $n = 1{\cdot}434$, the prism angle must be less than 44° 12′, for at this angle total reflection would take place. For a mineral of higher index the angle would have to be smaller still, as with diamond, $n = 2{\cdot}419$, where total reflection would take place at 24° 24′. On the other hand, more accurate results will be obtained if the prism angle is fairly near to the limit for the mineral being used.[a]

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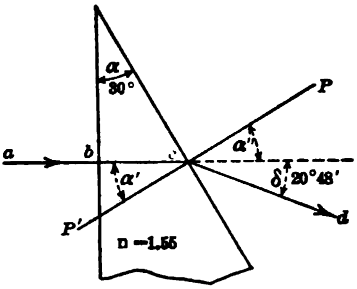

Refraction of Light through a Prism
Method of Perpendicular Incidence

Let Fig. 523 represent the cross section of such a prism. Let *a–b* represent a ray of light striking the face of this prism at 90° incidence. It will suffer no deviation in its path on entering the prism but will proceed with somewhat diminished velocity until it reaches *c*. In passing out of the prism at this point, from a denser to a rarer medium, the light will be deflected away from the normal to the surface, *P–P′*, making a deviation δ in the direction *c–d*. The data necessary for the calculation of the index of refraction under these conditions are the angle of the prism, α, and that of the deviation in the path of the light, δ. It is easy to see from the figure that α and α' are equal, for they are both parts of right-angled triangles having the angle $bP'c$ in common, and α'' is equal to α' because they are opposite angles. The angle of incidence, as defined in Art. **317**, is equal to $\alpha + \delta$ and the angle of refraction is equal to α. Therefore the usual formula $\frac{\sin i}{\sin r} = n$ becomes here $\frac{\sin \alpha + \delta}{\sin \alpha} = n$. In order to make a determination of the index of refraction, therefore, it is necessary to measure these two angles, α and δ.

The prism is mounted on a one-circle reflection goniometer and its angle α measured in the same way as an angle upon a crystal. The instrument is then adapted to the uses of a refractometer. For this purpose it is necessary to note that the telescope and vernier are both fastened to the outer rim of the instrument and move together. The graduated circle being clamped, the telescope tube is first moved to the position *T′*, Fig. 524, so that the rays from the collimator tube, *C*, passing the edge of the prism, cause the light signal to fall on the vertical cross-hair of the telescope. The inner circle being clamped the telescope is next moved through an arc of exactly 60° to position *T″* and then clamped. Next the prism is turned to the first position so that the light from *C* is reflected from its right-hand face and the signal *s* falls on the cross-hair of *T″*. In this position the normal, *N*, to the prism face, must bisect the angle between the axes of *C* and *T″*. The prism is now turned through an angle of exactly 60° to its second position, which brings the normal *N* exactly in line with the axis of the collimator tube. When this has been accomplished the graduated circle is securely clamped. The telescope may now be unclamped and moved without altering the position of the prism, and somewhere between T' and T'' a position T''' will be found where the refracted ray falls on the cross-hair of the telescope. The movement of the telescope from the position T''' back to T' gives the angle of deviation, or δ, of the light ray that has been refracted by the prism. In practice it is well to repeat the measurements both of α and δ several times and to go through all the operations of shifting the positions of the prism and telescope. If white light is used for illumination the refracted ray seen at T''' will appear as a narrow spectrum. To make an exact determination a monochromatic light (sodium light is best) must be employed.

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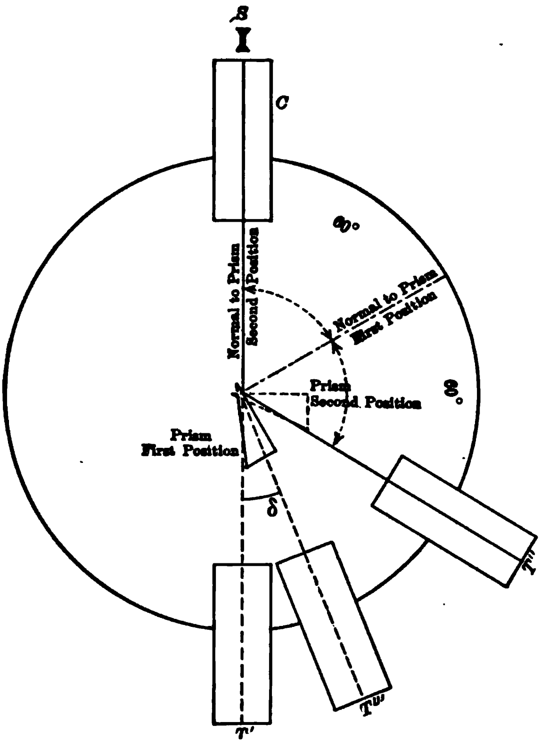
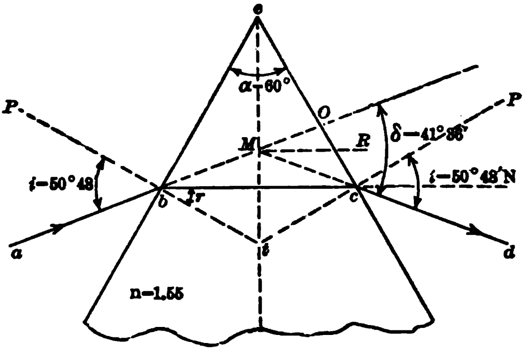

S
C
90°
Normal to Prism Second Position
Normal to Prism First Position
Prism Second Position
80°
Prism First Position
δ
T''
T'''
T'

Determination of Index of Refraction
Method of Perpendicular Incidence

2. *The Method of Minimum Deviation.* — This is the method that is most generally employed for determining indices of refraction by the use of prisms. It depends upon the principle that when a beam of light, *abcd*, Fig. 525, traverses a prism in such a way that the angles i and i' are equal, the beam suffers the minimum amount of deviation in its path of any possible course through the prism. This fact may be proven empirically by experimentation on the refractometer. In order to make a determination, the angle α of the prism is first measured on the goniometer. The angle of the prism with this method may be considerably larger than when the method of perpendicular

525



incidence is used. The prism is then turned with its edge to the left about as in the position shown in Fig. 526, the telescope unclamped and moved until the refracted ray appears in it. Now, turn the central post with the prism on it toward the left and follow the signal with the telescope. The position of minimum deviation is soon reached, when, on turning the prism, the signal seems to remain stationary for a moment and then moves away to the right, no matter in which direction the prism is turned. A little practice is needed to determine exactly the position of minimum deviation and the measurement should be made in a monochromatic light. When the telescope is properly placed at this point the graduated circle is clamped and the telescope turned until the direct signal from the collimator tube is fixed upon the vertical cross-hair. The angle between these two positions of the telescope is the same as the angle of deviation, or δ. The formula for making the necessary calculation from these measurements follows very simply from a comparison of Figs. 525 and 523. It may be imagined that Fig. 525 is composed of two prisms like Fig. 523 placed back to back. This results in doubling the angles α and δ so that the formula now becomes

$$n = \frac{\sin \frac{1}{2}(\alpha + \delta)}{\sin \frac{1}{2}\alpha}.$$

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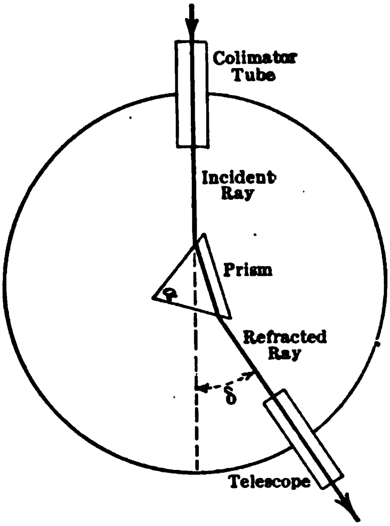
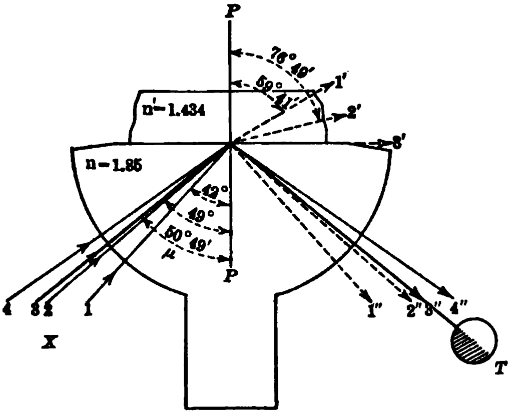


Determination of Index of Refraction
Method of Minimum Deviation

3. *The Method of Total Reflection.* — This method is based upon the principle that light cannot always pass from an optically dense into an optically rarer medium but at a certain angle, known as the critical angle, will suffer total reflection. The critical angle for any substance varies with the index of refraction of that substance as explained in Art. **323.** Consequently if we can measure this critical angle we can calculate the index of refraction of the substance. This method is particularly useful because the measurement can be made upon a single polished surface, which may be quite small in area. This measurement is made by means of an instrument, known as the Total Refractometer, a description of which will be found in Art. **352.** The essential feature of this instrument is a hemisphere of glass with a known, high index of refraction. The upper surface of the hemisphere is plane and should be accurately adjusted in a horizontal position. The mineral to be tested may be of any shape provided that some surface upon it has been ground plane and polished. A drop of some liquid of high index of refraction is placed between the surface of the glass hemisphere and the flat surface of the mineral. This serves to unite the two substances and dispel the thin layer of air that would otherwise separate them. The liquid should have an index of refraction intermediate between that of the glass and that of the mineral. As the liquid

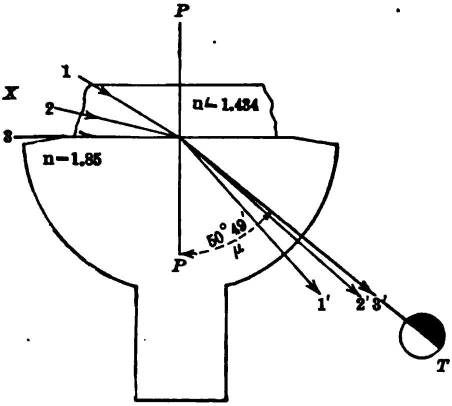
lies between the two substances in the form of a thin film with parallel surfaces whatever optical effect it has upon the light as it enters will be balanced by the opposite effect as the light leaves the film. So the optical effect of the liquid can be ignored. Fig. 527 represents a cross section of such a hemisphere with a mineral plate resting upon it. Let it be now supposed that by means of a mirror a beam of monochromatic light is thrown upon the apparatus from the direction of *X*. Rays 1 and 2 will suffer partial refraction at the dividing plane between the glass and the mineral to rays 1′ and 2′ and also partial reflection to rays 1″ and 2″. Ray 3 strikes the mineral at the critical angle for the combination of the glass and mineral and will in part be refracted at a 90° angle and emerge as ray 3′, just grazing the surface of the hemisphere. The greater part of ray 3 will however be reflected as ray 3″. Beyond this point, all the light must be totally reflected, thus 4 to 4″. If the optical axis of a telescope is now brought to the direction 3″, what appears to be a marked shadow will appear in the field of vision. One side will be illuminated by the total reflection of all rays beyond those of the critical angle while the other side will be distinctly darker since here a considerable amount of the light passed out into the mineral. The angle between the position of the shadow and the normal to the surface of the hemisphere, μ, Fig. 527, will be the critical angle for the combination of glass and mineral. As the index of refraction of the glass is known it is possible to calculate what the index of refraction of the mineral must be. If the mineral plate is transparent enough so that light may pass through it into the glass hemisphere another method of illumination may be used, as illustrated in Fig. 528. The reflecting mirror is so arranged that the light comes from the direction *X*. Rays 1 and 2 will be refracted to 1′ and 2′ and 3 which just grazes the surface to 3′. Beyond this point no light will pass into the hemisphere and a telescope placed with its axis along the line 3′ will show in its field a dark shadow. The contrast

527



Determination of Index of Refraction
Method of Total Reflection, I.

528



Determination of Index of Refraction
Method of Total Reflection, II.

between the light and dark portions of the field, by this method of illumination, is much stronger than by the one first described. The telescope is so placed that the line of the shadow exactly divides the angle between the diagonal cross-hairs of the eyepiece. The telescope is attached to a graduated circle from which the angle μ can be directly read. With each of these instruments comes ordinarily a table giving the indices of refraction corresponding to the different possible values of μ. This table can easily be converted into a curve plotted on co-ordinate paper in such a way that the index of refraction for a particular angle can be read at a glance. Further, the calculation can be made having given the index of refraction of the glass of the hemisphere and the value of μ for a special mineral plate. Let n' equal the index of refraction of the glass of the hemisphere and μ the critical angle measured; then the index of refraction of the mineral, $n, = \sin \mu \times n'$.*

328. Dispersion. — Thus far the change in direction which light suffers in reflection and refraction has alone been considered. It is further true that the amount of refraction differs for light of different wave-lengths, being greater for blue than for red. In consequence of this fact, if ordinary light be passed through a prism, as in Fig. 525, it will not only be refracted, but it will also suffer *dispersion* or be separated into its component colors, thus forming the *prismatic spectrum.*

This variation for the different colors depends directly upon their wave-lengths; the red waves are longer, their transverse vibrations are slower, and it may be shown to follow from this that they suffer less change of velocity on entering the new medium than the violet waves, which are shorter and whose velocity of transverse vibration is greater. Hence the refractive index for a given substance is greater for blue than for red light. The following are values of the refractive indices for diamond determined by Schrauf:

2·40845 red (lithium flame).
2·41723 yellow (sodium flame).
2·42549 green (thallium flame).

329. Spectroscope. — The instrument most commonly used for the analysis of the light by dispersion is familiar to all as the *spectroscope.* There

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* The derivation of this formula follows. From the ordinary law for the index of refraction we have, $\frac{\textit{velocity of light in air}}{\textit{velocity of light in mineral}} = \frac{\sin i}{\sin r} = n$. But when the critical angle is reached $i = 90°$ and $\sin i = 1$. Therefore we may substitute and have $n = \frac{1}{\textit{velocity of light in mineral}}$ or $\textit{velocity of light in mineral} = \frac{1}{n}$. Further, we may derive in the same way for the highly refracting glass of the hemisphere whose refractive index, n', is known, the expression, $\textit{velocity of light in glass} = \frac{1}{n'}$. Further, we have in the case of the light attempting to pass from the glass (optically denser medium) into the mineral the expression,

$$\frac{\textit{velocity of light in mineral}}{\textit{velocity of light in glass}} = \frac{\sin 90°}{\sin \mu} \text{ (measured on instrument).}$$

By substituting this becomes

$$\frac{\frac{1}{n}}{\frac{1}{n'}} = \frac{\sin 90°}{\sin \mu} = \frac{1}{\sin \mu}$$

or

$$\frac{1}{\sin \mu} = \frac{n'}{n} \quad \text{or} \quad n = \sin \mu \times n'.$$

are a number of varieties of spectroscopes made, the simplest of which consists of a glass prism mounted at the center of the instrument with two tubes pointing away from it. The light from the given source is received through a narrow slit in the end of one tube and made to fall as a plane-wave (that is, as a "pencil of parallel rays") upon one surface of a prism at the center. The light is dispersed by its passage through the prism and the spectrum produced is viewed through a suitable telescope at the end of the second tube.

If the light from an incandescent solid — which is "white hot" (Art. **314**) — is viewed through the spectroscope, the complete band of colors of the spectrum is seen from the red through the orange, yellow, green, blue, to the violet. If, however, the light from an incandescent vapor is examined, it is found to give a spectrum consisting of bright lines (or bands) only, and these in a definite position characteristic of it — as the yellow line (double line) of sodium vapor; the more complex series of lines and bands, red, yellow, and green, characteristic of barium; the multitude of bright lines due to iron vapor (in the intensely hot electric arc), and so on.

330. Absorption. — Of the light incident upon the surface of a new medium, not only is part reflected (Art. **316**) and part transmitted and refracted (Art. **317**), but, in general, part is also *absorbed* at the surface and part also during the transmission. Physically expressed, absorption in this case means the transformation of the ether-waves into sensible heat, that is, into the motion of the molecules of the body itself.

The color of a body gives an evidence of this absorption. Thus a sheet of red glass appears red to the eye by *transmitted light*, because in the transmission of the light-waves through it, it absorbs all except those which together produce the effect of red. For the same reason a piece of jasper appears red by *reflected light*, because it absorbs part of the light-waves at the surface, or, in other words, it reflects only those which together give the effect of this particular shade of red.

Absorption in general is *selective* absorption; that is, a given body absorbs particular parts of the total radiation, or, more definitely, waves of a definite wave-length only. Thus, if transparent pieces of glass of different colors are held in succession in the path of the white light which is passing into the spectroscope, the spectrum viewed will be that due to the selective absorption of the substance in question. A layer of blood absorbs certain parts of the light so that its spectrum consists of a series of absorption bands. Certain rare substances, as the salts of didymium, etc., have the property of selective absorption in a high degree. In consequence of this, a section of a mineral containing them often gives a characteristic absorption spectrum.

This latter property may be made use of in testing certain minerals, more especially those that contain the rare earths or uranium. These give characteristic absorption bands in the spectrum. They may be tested by passing a strong white light through a thin section of the mineral and observing the resulting spectrum by means of a direct vision spectroscope. Often a better result will be obtained by illuminating the surface of the mineral and testing the reflected light for absorption bands. The light will have sufficiently penetrated the mineral before reflection to have had some of it absorbed. These tests can be made best by some sort of a microspectroscope, which will give a clear spectrum superimposed upon a scale of wave-lengths.*

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* For details of this method of testing minerals see Wherry, Smithsonian Misc. Coll., **65**, No. 5, 1915.

The dark lines of the solar spectrum, of which the so-called Fraunhofer lines are the most prominent, are due to the selective absorption exerted by the solar atmosphere upon the waves emitted by the much hotter incandescent mass of the sun.

331. Diffraction. — When monochromatic light is made to pass through a narrow slit, or by the sharp edge of an opaque body, it suffers *diffraction*, and there arise, as may be observed upon an appropriately placed screen, a series of dark and light bands, growing fainter on the outer limits. Their presence is explained (see Arts. **335, 336**) as due to the interference, or mutual reaction, of the adjoining systems of waves of light, that is, the initial light-waves, and further, those which have their origin at the edge or sides of the slit in question. It is essential that the opening in the slit should be small as compared with the wave-length of the light. If ordinary light is employed, the phenomena are the same, and for the same causes, except that the bands are successive colored spectra.

Diffraction spectra, explained on the principles alluded to, are obtained from diffraction gratings. These gratings consist of a series of extremely fine parallel lines (say, 15,000 or 20,000 to an inch) ruled with great regularity upon glass, or upon a polished surface of speculum metal. The glass grating is used with transmitted, and the speculum grating with reflected, light; the Rowland grating of the latter kind has a concave surface. Each grating gives a number of spectra, of the first, second, third order, etc. These spectra have the advantage, as compared with those given by prisms, that the dispersion of the different colors is strictly proportional to the wave-length.

332. Double Refraction. — As implied in Art. **320**, all crystallized substances may be divided into two principal optical classes, viz.: *isotropic*, in which light has the same velocity no matter what the direction of its propagation, and *anisotropic*, in which the velocity of light in general varies with the direction of propagation. The anisotropic class is further divided into *uniaxial*, which includes crystals of the tetragonal and hexagonal systems, and *biaxial*, which includes crystals of the orthorhombic, monoclinic, and triclinic systems. The characters of these various optical classes will be explained in detail further on.

In the discussion of Art. **317**, applying to isotropic media, it was shown that light-waves passing from one medium into another, which is also isotropic, suffer simply a change in wave-front in consequence of their change in velocity. In anisotropic media, however, which include all crystals but those of the isometric system, there are, in general, two wave-systems propagated with different velocities and only in certain limited cases is it true that the light-ray is normal to the wave-front. This subject cannot be adequately explained until the optical properties of these media are fully discussed, but it must be alluded to here since it serves to explain the familiar fact that, while with glass, for example, there is only one refracted ray, many other substances give two refracted rays, or, in other words, show *double refraction*.

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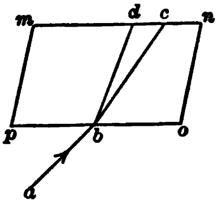

The most familiar example of this property is furnished by the mineral calcite, also called on account of this property "doubly-refracting spar." If *mnop* (Fig. 529) be a cleavage piece of calcite, and a ray of light meets it at *b*, it will, in passing through, be divided into two rays, *bc*, *bd*. For this reason, a dark spot or a line seen through a piece of calcite ordinarily appears double. As implied above, the same property is enjoyed by all crystallized minerals, except those of the isometric system. The wide separation of the two refracted rays by calcite, which makes the phenomenon so striking, is a consequence of the large difference in the values of its indices of refraction; in other words, as technically expressed, it is due to the *strength* of its double refraction, or its *birefringence*.

333. Double refraction also takes place in the anisotropic media just mentioned, in the majority of cases, even when the incident light is perpendicular to the surface. If the medium belongs to the uniaxial class (see p. 253, *et seq.*), one of the rays always retains its initial direction normal to the surface; but the other, except in certain special cases, is more or less deviated from it. With a biaxial substance, further, both rays are usually refracted and bent from their original direction. In the case of both uniaxial and biaxial media, however, it is still true that the normal to the wave-front remains unrefracted with perpendicular incidence.

334. Interference of Waves in General. — The subject of the interference of light-waves, alluded to in Art. **331**, requires detailed discussion. It is one of great importance, since it serves to explain many common and beautiful phenomena in the optical study of crystals.

Referring again to the water-waves spoken of in Art. **308**, it is easily understood that when two wave-systems, going out, for example, from two centers of disturbance near one another, come together, if at a given point they meet in the same phase (as crest to crest), the result is to give the particle in question a double amplitude of motion. On the other hand, if at any point the two wave-systems come together in opposite phases, that is, half a wave-length apart, the crest of one corresponding to the trough of the other, they interfere and the amplitude of motion is zero. Under certain conditions, therefore, two sets of waves may unite to form waves of double amplitude; on the other hand, they may mutually interfere and destroy each other. Obviously an indefinite number of intermediate cases lie between these extremes. What is true of the waves mentioned is true also of sound-waves and of wave-motion in general. A very simple case of interference was spoken of in connection with the discussion of the waves carried by a long rope (Art. **310**).

335. Interference of Light-waves. — Interference phenomena can be most satisfactorily studied in the case of light-waves. The extreme cases are as follows: If two waves of like length and intensity, and propagated in the same direction, meet in the same phase, they unite to form a wave of double intensity (double amplitude). This, as stated in Art. **311**, will cause an increase in the intensity of the light. If, however, the waves differ in phase by half a wave-length, or an odd multiple of this, they *interfere* and extinguish each other and no light results. For other relations of phase they are also said to interfere, forming a new resultant wave, differing in amplitude from each of the component waves. In the above cases monochromatic light-waves were assumed (that is, those of like length). If ordinary white light is used interference for certain wave-lengths may result with the consequent subtraction of the corresponding color from the white light and so give rise to various spectrum colors.

336. Illustrations of Interference. — A simple illustration is afforded by the bright colors of very thin films or plates, as a film of oil on water, a soap-bubble, and like cases. To understand these, it is only necessary to remember that the incident light-waves are reflected in part from the upper and in part from the lower surface of the film or plate. The rays that are reflected from the under surface of the very thin film (see Fig. 530) having traveled a greater distance and with a different velocity will, when they unite with those rays reflected from the upper surface, show in general a different phase. For some particular wave-length of light this difference is likely to be exactly a half wave-length or some odd multiple of this amount and so the corresponding color will be eliminated (assuming that ordinary white light is being used) and its complementary color will be seen. It is to be noted that the phenomena of interference by reflection are somewhat complicated by the fact that there is a reversal of phase (that is, a loss of half a wave-length) at the surface that separates the medium of greater optical density from the rarer one. Hence the actual relation in phase of the two reflected rays, as AC, BD (supposing them of the same wave-length) is that determined by the retardation due to the greater length of path traversed by BD, together with the loss of a half wave-length due to the reversal of phase spoken of. As shown in the figure, there are also two transmitted waves which also interfere in like manner.

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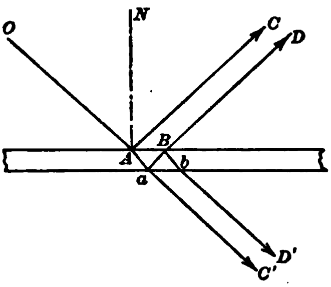

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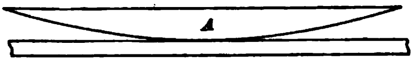

A plano-convex lens of long curvature, resting on a plane glass surface (Fig. 531), and hence separated from it, except at the center, by a film of air of varying thickness, gives by reflected monochromatic light a dark center and about this a series of light and dark rings, called *Newton's rings*. The dark center is due to the interference of the incident and reflected waves, the later half a wave-length behind the former. The light rings correspond to the distances where the two sets of reflected waves meet in the *same phase*, that is (noting the explanation above) where the retardation of those having the longer path is a half wave-length or an odd multiple of this ($\frac{1}{2}\lambda$, $\frac{3}{2}\lambda$, $\frac{5}{2}\lambda$, etc.). Similarly the dark rings fall between these and correspond to the points where the two waves meet in opposite phase, the retardation being a wave-length or an even multiple of this. The rings are closer together with blue than with red because of the smaller wave-length of blue light. In each of the cases described the ring is properly the intersection on the plane surface of the cone of rays of like retardation.

In ordinary white light we get, instead of the alternate light and dark rings described above, a series of colored bands. If the illumination was originally by sodium light the position of the dark rings indicates where light for that particular wave-length has been extinguished through interference. When white light is used the conditions in respect to its component having the yellow sodium-light wave-length have not changed and this light will still be eliminated at the same points, but now, instead of dark rings, we get rings having the complementary color blue. If our original illumination was by means of a red light the dark rings would have had different positions from those produced in sodium light. And again when white light is used red light is eliminated at those points and its complementary color shows. In this way we obtain a series of *colored rings*, each showing the successive colors of the spectrum. The series of the spectrum colors are repeated a number of times due to successive interferences produced by differences of phase of $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$, etc., wave-lengths. The different series are distinguished as of the first, second, third, etc., order; for a given color, as red, may be repeated a number of times. The interference rings for different colored lights are not evenly spaced, the rings shown in blue light being, for instance, closer together than for red. Consequently after three or four repetitions of the spectrum bands the different interference rings begin to overlap one another and the resulting colors become fainter and less pure. Ultimately this overlapping becomes so general that the effect of color is lost and white light, the so-called white of the higher orders, is shown.

Another most satisfactory illustration of the interference of light-waves is given by means of the diffraction gratings spoken of in Art. 331.

Other cases of the composition of two systems of light-waves will be considered after some remarks on polarized light.

337. Polarization and Polarized Light. — Ordinary light is propagated by transverse vibrations of the ether which may take place in any direction as long as it is at right angles to the line of propagation. The direction of vibration is constantly changing and the resulting disturbance of the ether is a complex one. A ray of ordinary light will be symmetrical, therefore, only to the line of its propagation.

Plane-polarized light, on the other hand, as stated briefly in Art. **311**, is propagated by ether-vibrations which take place *in one plane only*. The change by which ordinary light is converted into a polarized light is called *polarization*, and the plane at right angles to the plane of transverse vibration is called the *plane of polarization*.*

Polarization may be accomplished (1) by reflection and by single refraction, and (2) by double refraction.

338. Polarization by Reflection and Single Refraction. — In general, light which has suffered reflection from a surface like that of polished glass is more or less completely polarized; that is, the reflected waves are propagated by vibrations to a large extent limited to a single plane, viz., (as assumed) the plane normal to the plane of incidence, which last is hence the plane of polarization. Furthermore, in this case, the light transmitted and refracted by the reflecting medium is also in like manner partially polarized; that is, the vibrations are more or less limited to a single plane, in this case a plane at right angles to the former and hence coinciding with the plane of incidence. For instance, in Fig. 532, let *a–b* represent an incident light ray in which the vibrations are taking place in all possible transverse directions as represented

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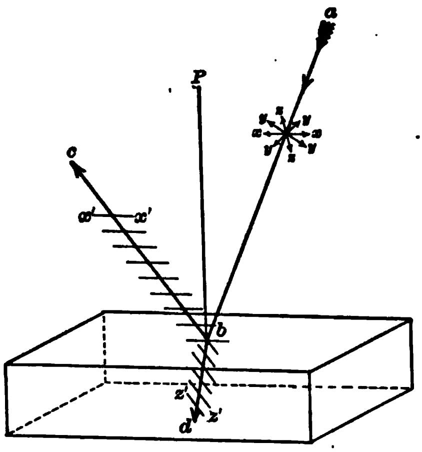

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[*] It is necessary to keep clear the distinction between the *plane of polarization* and the plane in which the vibrations take place. All ambiguity is avoided by speaking uniformly of the *vibration-plane* of the light.

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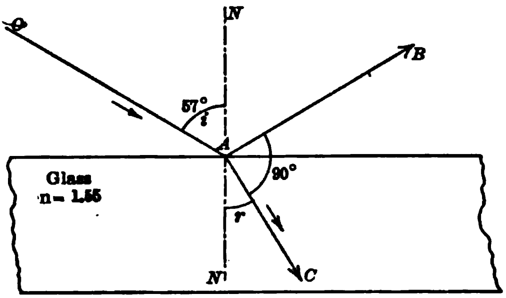

Brewster's Law

by the arrows, x–x, y–y, and z–z. When this ray strikes the polished surface at b light with vibrations parallel to x–x will be reflected along b–c and other vibrations near to x–x in direction will be shifted to this direction so that the reflected ray will be largely polarized. In a similar manner the light having z–z vibrations will enter the transparent substance as the refracted ray $b-d$ and other vibrations will be shifted to this direction so that the refracted ray is also largely polarized and in a plane at right angles to that of the reflected ray. Light reflected from a polished and transparent surface is not completely polarized but there is an angle of incidence for every substance at which the amount of polarization will be at its maximum. This will happen, as illustrated in Fig. 533, when the angle between the reflected and refracted rays AB and AC equals 90°. It is evident from a consideration of the figure that the angle r is the complement of i; hence the formula $\frac{\sin i}{\sin r} = n$ becomes in this case

$$\frac{\sin i}{\cos i} = \tan i = n.$$

This law, established by Brewster, may be stated as follows:

The angle of incidence for maximum polarization is that angle whose tangent is the index of refraction of the reflecting substance. For crown glass this angle is about 57° (see Fig. 533). If light suffers repeated reflections from a series of thin glass plates, the polarization is more complete, though its intensity is weakened. Metallic surfaces polarize the light very slightly.

339. Polarization by Double Refraction. — When light in passing through a crystalline medium is doubly refracted (Art. **332**) or divided into two sets of waves, it is always true that both are completely polarized and in planes at right angles to each other. This subject can only be satisfactorily explained after a full discussion of the properties of anisotropic crystalline media, but it may be alluded to here since this principle gives the most satisfactory method of obtaining polarized light. For this end it is necessary that one of the two wave-systems should be extinguished, so that only that one due to a single set of vibrations is transmitted. This is accomplished by natural absorption in the case of tourmaline plates and by artificial means in the nicol prisms of calcite.

340. Polarized Light by Absorption. — Light passing through a strongly colored but transparent thin section of a tourmaline crystal — the section being cut parallel to the vertical crystallographic axis — will be almost completely polarized. This can be easily demonstrated in the following way. Select a polished floor surface, or a table top and stand in such a position that light from a window is reflected from the polished wood to the eye. Look at this reflected light through the tourmaline section, holding it first with the direction of the *c* crystal axis in a horizontal position and then turning the section until the *c* axis becomes vertical. The light passing into the tourmaline section is in considerable part polarized through its reflection from the wood surface and possesses a horizontal vibration direction. It will be noted that when the *c* axis of the tourmaline is horizontal the section readily transmits light but when this axis is vertical the section becomes practically opaque. The crystal structure of the tourmaline is such that light entering it is broken up into two rays (*i.e.*, it is doubly refracted), one of which has its vibrations parallel to the *c* axis, while the vibrations of the other lie in the plane of the horizontal crystal axes. From the foregoing experiment it is obvious that the light vibrating parallel to the *c* axis is readily transmitted by the crystal but that the other ray, vibrating in the horizontal axial plane, is almost completely absorbed. Under these conditions it is clear that the transmitted light belongs almost wholly to one ray, the vibrations of which take place in a single direction. In other words, the light transmitted by such a tourmaline section is *polarized.*

If two such sections of tourmaline are available it is instructive to make the following experiment with them. Place them together, first with their *c* axes parallel to each other, and then turn one section upon the other until these axes are at right angles to each other. In the first case, the light comes through the sections because the vibration planes of the transmitted rays in the two sections are parallel to each other. In the second case, all light is cut off because now these two vibration planes are at right angles to each other, the light that did get through the first section being wholly absorbed in the second.

341. Polarized Light by Double Refraction. — Calcite, as already stated in Art. **332**, possesses in an unusual degree the power to doubly refract light. If we take a cleavage block of clear calcite (Iceland spar) and look at an image through it, such as a dot or line drawn on a piece of paper, the image will appear double. If we take a card and make in it a pinhole, place the card upon one face of a cleavage rhombohedron and, looking through the calcite, hold it up against a source of light, we will observe two bright dots. Now if we look in the same way at the light reflected from a polished wooden surface, as described in the preceding article, we will find that when a line bisecting the acute angles of the rhombic face of the cleavage block is horizontal one of these images is bright while the other is almost invisible. If we then turn the block so that the line bisecting the obtuse angles of the rhombic face is horizontal the first image will fade while the second becomes bright. Remembering that the light reflected from the polished wooden surface is largely polarized with a horizontal vibration direction, it becomes evident from this experiment that the two rays into which the light is broken up in passing through the calcite are polarized and that their planes of vibration are at right angles to each other and respectively bisect the angles of the rhombic face of the cleavage block. As the double refraction of calcite is strong, it follows that the indices of refraction of the two rays show considerable differences. This fact is taken advantage of in constructing a prism from calcite in such a way as to wholly eliminate one of these rays and so, as only the other ray can come through the prism, effectively polarizing the light that emerges.

The prism referred to above is called the *Nicol Prism* or simply the *nicol.* A full explanation of the nicol cannot be made at this time, as there would be required a knowledge of the optical properties of hexagonal crystals, but a description may be given enabling one to understand its construction and uses. In Fig. 534 is represented a cleavage rhombohedron of calcite with its edges vertical. Let *d* represent a point of light underneath the rhombohedron. Light coming from *d* will be broken into two rays whose paths through the rhombohedron are shown by the lines *o* and *e*. As shown above, these two rays are polarized, with vibration directions as indicated by the double arrows in the top view in Fig. 534. In the construction of a nicol, the top and bottom surfaces of such a cleavage rhombohedron are ground and polished so that they make angles of 68° with the vertical edges. Then the block is cut in two along the diagonal *a–f*, as shown in Fig. 535. These two surfaces, after being polished, are cemented together by means of a thin layer of Canada balsam. Let us assume that a ray of light enters the prism from below, as shown in Fig. 535. It is broken up into the rays *o* and *e*. The ray *o* travels with the slower velocity, has therefore the higher index of refraction, and shows a greater deviation from the original path. The Canada balsam has a lower index of refraction than ray *o*, which, therefore, when it strikes the layer of balsam, is attempting to pass from an optically dense into a rarer medium. The construction of the prism is such that this ray meets the layer of balsam at an angle greater than the critical angle for this optical combination and suffers therefore total reflection toward the side of the prism, and will be absorbed by whatever fastening holds the nicol. The second ray *e* passes through the prism with almost no deviation from its original course. Its index of refraction and that of the Canada balsam are nearly the same, hence the ray suffers almost no deflection at this point and passes out of the upper face of the prism. The light, therefore, that emerges from a nicol belongs wholly to one ray and is all vibrating parallel to the shorter diagonal of the rhombic end surface. It should be noted, however, that some prisms are made in a different way and that the above statement concerning the plane of vibration of the light emerging from the prism may not always hold true. It is always wise to test the plane of vibration of a nicol by looking through it at the floor or a table top as previously described. The prism will show bright when its plane of vibration is horizontal, thus corresponding to the plane of vibration of the reflected light.

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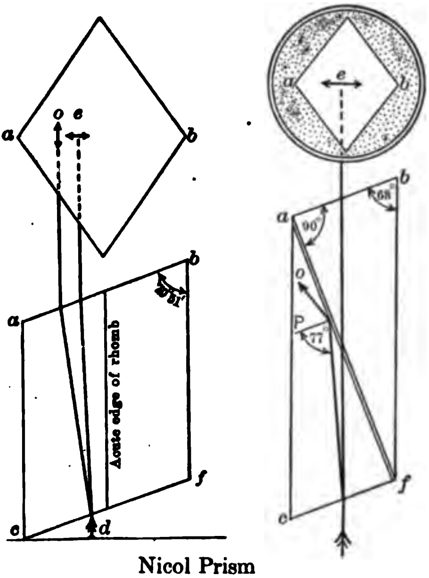

Nicol Prism

342. Polariscope. Polarizer. Analyzer. — The combination of two nicols, or other polarizing contrivances, between which transparent mineral sections may be examined in polarized light is called, in general, a *polariscope;* the common forms of which are described later. In any polariscope the lower prism, or other contrivance, which polarizes the light given from the outside source is called the *polarizer;* the upper prism is the *analyser.* If these prisms have their vibration-planes at right angles to each other, they are said to be *crossed;* the incident light polarized by the polarizer will then be extinguished by the analyzer; briefly, under these conditions it is said to suffer *extinction.*

343. Interference of Plane-polarized Waves. Interference Colors. — When sections of doubly refracting minerals are examined in polarized light certain interference effects are commonly obtained that are of great importance. As shown in Art. **341,** calcite when it doubly refracts light also polarizes the two rays and in planes that are at right angles to each other. In general, this is true of sections of doubly refracting minerals. Consider, then, what takes place when a general section of a doubly refracting mineral is placed in a polariscope between the polarizer and analyzer the planes of vibration of which are at right angles to each other. In Fig. 536 let the rectangular outline represent such a section. The double arrows marked *o* and *e* show the two possible directions of vibration of light in the section. The direction *P–P′* represents the plane of vibration of light which emerges from the polarizer below and *A–A′* shows the direction in which light must vibrate when it emerges from the analyzer above. In the first case to be considered the directions *o* and *e* are taken as parallel to *P–P′* and *A–A′* respectively. The light that enters the section from below must all vibrate parallel to the direction *P–P′*. It enters the mineral section and must vibrate there as the ray labeled *o*. There will be no ray in the mineral vibrating parallel to the direction *e*, as a vibration parallel to *o* cannot be resolved into another at right angles to it. The light will leave the section, therefore, still vibrating parallel to *P–P′* and enter the analyzer above. It will, however, be entirely reflected in the analyzer at the layer of balsam since only light vibrating parallel to *A–A′*, which is at right angles to *P–P′*, can emerge from the analyzer. Consequently, when such a section has its planes of vibration parallel to those of the polarizer and analyzer, the section will appear dark. The same reasoning holds true when the section is turned to a position at 90° from the first. Consequently with such a section there are four positions at 90° to each other in which it appears dark during its complete rotation upon the stage of the polariscope. At such positions the section, is said to be *extinguished.*

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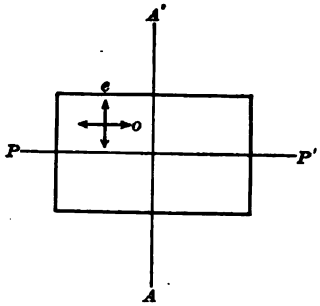

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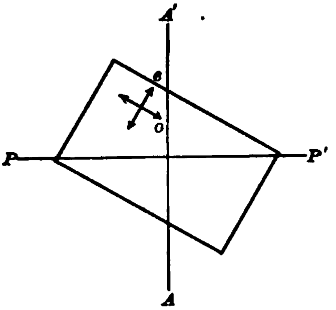

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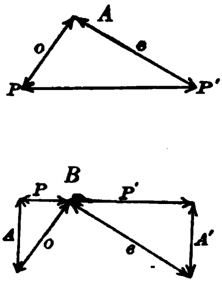

Next consider what happens when the vibration directions of the section are at oblique angles to those of the polarizer and analyzer. In Fig. 537 let *o* and *e* represent the directions of vibration in a section which makes some oblique angle with the directions *P–P′* and *A–A′*. In Fig. 538*A* let the line *P–P′* represent the direction and amplitude of the vibration of the light entering the mineral section having come through the polarizer below. The light must vibrate in the mineral in directions parallel to *o* and *e*, Fig. 537. The vibration *P–P′* will therefore be resolved into two vibrations at right angles to each other which will be parallel respectively to *o* and *e*. In Fig. 538*A* the lines *o* and *e* representing the direction and amplitudes of such vibrations are found by the application of the principle of the parallelogram of forces. The two rays emerge from the mineral section vibrating in these two planes and enter the analyzer above. Since the planes of vibration in the analyzer are parallel to *A–A′* and *P–P′* these two rays *o* and *e* will resolve each into two new rays which will vibrate now parallel to *A–A′* and *P–P′*. The two rays labeled *P* and *P′* in Fig. 538*B* will be absorbed by the analyzer but the rays marked *A* and *A′* will emerge and meet the eye. The section in this position, therefore, will be illuminated. Consequently the section will be illuminated in all possible positions in which the directions of vibration of the light in the mineral make inclined angles with the directions of vibration of the polarizer and analyzer. It is easy to prove that this illumination will be at its maximum when the angle between the directions *o* and *e* and *A–A′* and *P–P′* is 45°. In addition to being illuminated, the section, if thin, will also be colored. This interference color, as it is called, of mineral sections when examined in a polariscope, now needs explanation.

The amount of refraction which any ray of light suffers on entering a mineral depends upon two things, namely, the angle of incidence at which the light enters and the index of refraction of the mineral. In the case of a doubly refracting mineral we have a light ray entering the section at a given angle of incidence and then being broken up into two polarized rays which have different angles of refraction and so travel different paths. Consequently the indices of refraction for these rays must be different and from this it follows that the two rays must have different velocities and will therefore emerge from the mineral in different phases. Light waves having different phases will in a greater or less degree interfere with each other and in case of light of certain wave-lengths, *i.e.*, light of some particular color, the interference may lead to extinguishment of that particular wave-length. If one particular color is subtracted in this way from white light the result will be to produce the complementary color and under such conditions the section will no longer be white but colored. The color of thin sections of minerals when seen under the polariscope is known as their *interference color*. To develop this subject further use will be made of an accessory of the microscope known as the Quartz Wedge.

The *Quartz Wedge* consists simply of a very thin tapering wedge the faces of which are approximately parallel to the prism of a quartz crystal. It is mounted on a narrow glass plate, Fig. 539, A. The plate is generally marked with the letter *Q* (quartz) and with an arrow. If the wedge is cut, as is usually the case, with its longer direction at right angles to the vertical axis of a quartz crystal, the arrow is marked *X* (or $\mathfrak{a}$), which indicates that of the two directions of vibration of light in the wedge the one which is parallel to this direction is that of the ray which is propagated with greater velocity. Some wedges are cut with their longer direction parallel to the vertical axis of quartz, and the arrow in this case would be marked *Z* (or $\mathfrak{c}$), which indicates that this is the direction of vibration of the slower ray. It is absolutely essential that the optical orientation of the wedge be known.

The quartz wedge furnishes a prismatic section of varying thickness and of known orientation and may be used to study the effects of polarized light on plates (short sections of the wedge) of different thicknesses. Take the simplest form of polariscope, a combination of polarizer and analyzer without

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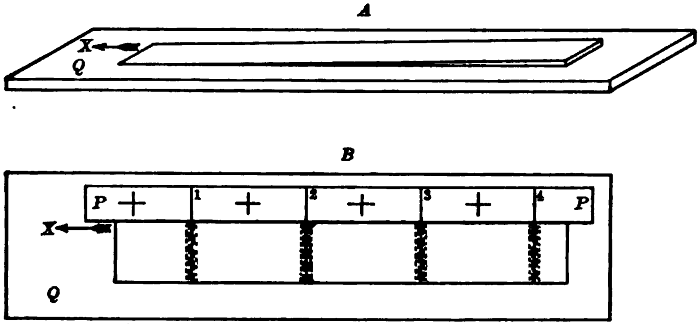

Quartz Wedge

lenses, and arrange it so that the vibration planes of the instrument are crossed. Illuminate with ordinary light and on the stage of the instrument place a quartz wedge with its *X* direction parallel to the plane of vibration of the polarizer. The light in entering the quartz will vibrate parallel to the *X* direction and without changing its plane of vibration will pass through the quartz and up into the upper nicol where it will suffer total reflection. Hence the wedge in this position will appear dark throughout its length. A similar result will be obtained when the *X* direction of the wedge is placed parallel to the vibration plane of the analyzer. But if the wedge is turned so that its *X* direction makes an angle of about 45° with the plane of vibration of the polarizer the wedge will exhibit a series of beautiful interference colors, arranged in transverse bands, the nature of which will be discussed in a later paragraph. If the wedge is turned from this 45° position the colors become less and less brilliant as the position of extinction is neared.

As preliminary to another experiment, paste a narrow strip of paper, *P–P*, Fig. 539, B, on the top, but to one side, of a quartz wedge. Place this on the stage of a polariscope (without lenses) and illuminate with diffused sodium light. When the wedge is examined under these conditions it will be found that it shows extinction when its vibration directions are parallel to those of the polariscope but at the 45° position it will show transverse dark bands upon a yellow field. The number of these bands will depend upon the thickness of the wedge; usually there will be two or three, although for this experiment it is interesting to have a longer and proportionally thicker wedge than those commonly supplied, so as to have more bands appearing. Mark on the strip of paper the position of each band, as illustrated in Fig. 539, B and number them, starting at the band nearest the thinner end of the wedge. The number 1 band marks the place where the faster of the two rays, into which the quartz breaks up the sodium light, has gained exactly one wave length in its phase over the slower ray. At the point marked 2 the gain is two wavelengths, etc.

In explaining the phenomenon just described, reference is made to Fig. 540 in which it is assumed that *P–P′* is the plane of the polarizer and *A–A′*

is the plane of the analyzer, and a quartz wedge is between them at such an angle that the direction of the vertical crystal axis lies parallel to *C–C′*. If we explain the action of light in the wedge in a purely mechanical way we may say, let the amplitude of vibration of an ether particle before the light has entered the wedge be represented in the figure by the line *O–p*. The vibration may be likened to that of a pendulum, swinging back and forth from *p* to *p′*. If the impact, or disturbance, of an ether particle is communicated to the ether particles of the quartz when it is at *O* at the middle of an oscillation from *p* to *p′*, there will result two disturbances, one to *r* parallel to *C–C′* and the other to *s* at right angles thereto. The amplitude of the vibrations represented by *O–r* and *O–s* are determined by the parallelogram of forces, as indicated by the dotted lines in the figure. During the passage of these two rays through the quartz the one whose vibrations are represented by *s–s′* travels the faster and it is assumed that the thickness of the quartz wedge at the place under consideration is such that, on emerging, this ray is just one wave-length ahead of the one whose vibrations are parallel to *r–r′*. Now, when one ray is exactly one wavelength ahead of another (it may be two, three or any exact number of wavelengths) the conditions are such, that, at the middle of the vibration, when an ether particle of the ray *s–s′* is just starting from *O* to *s*, an ether particle of the ray *r–r′* will be just starting from *O* to *r*. Now consider the effects produced by the simultaneous impacts in the directions *O* to *s* and *O* to *r* upon the ether particles of the calcite constituting the analyzer. A vibration from *s′* to *s* acting at *O* will displace the ether particles of the calcite to *σ* and *σ′*. Likewise a vibration from *r′* to *r* acting at *O* will displace the ether particles to *ρ* and *ρ′*. Two of these resulting disturbances, namely *O–σ′* and *O–ρ′*, are easily disposed of, for being in the plane *P–P′* their effects cannot pass beyond the layer of Canada balsam in the nicol. The other disturbances *O–σ* and *O–ρ* are both in the plane *A–A′* and can emerge from the nicol, but since the ether particles at *O* are acted upon simultaneously by forces of equal magnitude acting in opposite directions no disturbance can take place and under these conditions the section is dark. From the above it follows that, when a section of a doubly refracting mineral is observed between crossed nicols with its vibration planes making some oblique angle

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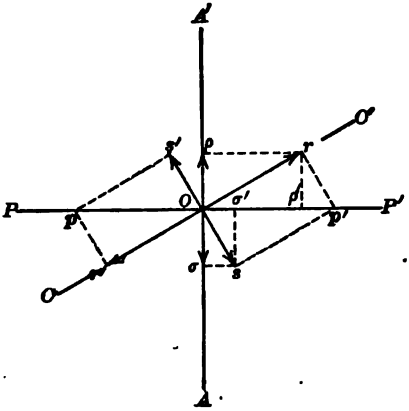

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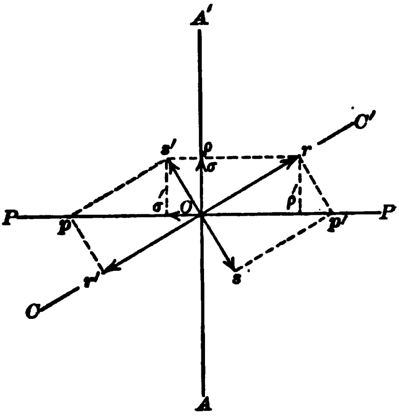

with the vibration planes of the nicols, complete interference will take place for some particular wave-length of light whenever the two polarized rays corresponding to this color emerge from the section in the same phase.

It is well to consider next the effects that result when, with the planes of vibration of the nicols crossed, light travels through such thicknesses of the quartz wedge that one ray gains ½, $\frac{3}{2}$, or some other half wave-length over the second ray. Let it be supposed, Fig. 541, that at *O*, the middle of an oscillation from *p* to *p'*, the impact is communicated to the ether particles of a quartz section the vertical crystal axis of which lies parallel to the direction *C*–*C'*. There will result two disturbances in the quartz, one from *O* to *r* and the other from *O* to *s*. After traversing the section the phases of the two rays differ by one half wave-length so that when the direction of the first oscillation is from *O* to *r*, that of the other will be from *O* to *s'*. The impulse *O*–*r* gives rise in the analyzer to two disturbances *O*–ρ and *O*–ρ'. The impulse *O*–*s'* results in the two displacements *O*–σ and *O*–σ'. Of these disturbances *O*–ρ' and *O*–σ' do not extend beyond the layer of Canada balsam of the analyzer, while *O*–ρ and *O*–σ, both of equal magnitude and vibrating in the plane *A*–*A'*, are additive and give rise to a disturbance and the sensation of light. Hence, in the experiment with the quartz wedge in sodium light, there are areas of light between the dark bands, Fig. 539, B.

An instructive experiment with the wedge should also be tried with sodium light illumination but with the planes of vibration of the polariscope parallel to each other instead of crossed as in the previous cases. If light traverses such a thickness of quartz that, on emerging, one ray has gained one half of a wave-length over the other the conditions up to the time the vibrations enter the analyzer will be the same as in the previous case. The vibrations, however, which can now pass through the analyzer result, Fig. 542, from the disturbances *O*–ρ' and *O*–σ', and these acting on an ether particle in opposite directions but with unequal force would produce a disturbance in the direction *O*–ρ' and, therefore, give rise to the sensation of light. A wedge with the direction of the vertical crystal axis about parallel to *C*–*C'* will appear yellow throughout its entire length. This will not be the case, however, if the wedge is turned so that the vertical axis makes an angle of 45 with the plane of polarization, Fig. 543, for then the forces acting upon an ether particle at *O* are *O*–ρ' and *O*–σ, which, being equal

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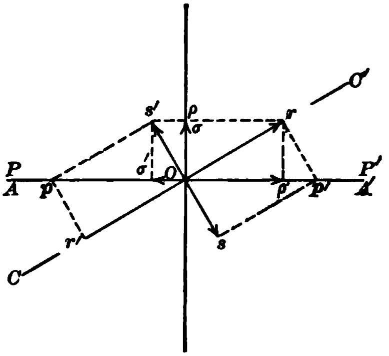

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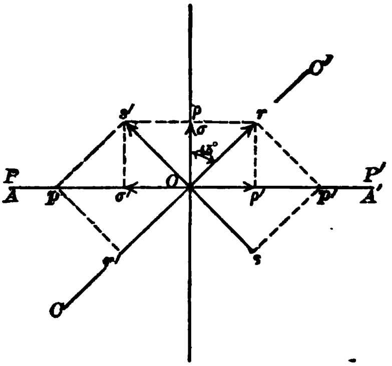

and in opposite directions, will neutralize each other and therefore will not produce any sensation of light. A wedge in the 45° position will therefore show a series of dark bands, the first, starting from the thin end of the wedge, being where one ray has gained $\frac{1}{2}$ wave-length, the second where it has gained $\frac{3}{2}$ wave-lengths, etc., over the second ray. In Fig. 539, B, the positions of the bands in this experiment are indicated by the crosses marked on the strip of paper pasted upon one side of the quartz wedge. The lines and crosses on this paper strip indicating gains of whole and one half wave-lengths for yellow light may now serve as starting points for further considerations.

For the next experiment use a microscope with crossed nicols, a number 3 or 4 objective, and illuminate with ordinary light; place the wedge in the 45° position and focus on that part of it opposite the first line drawn on the paper strip. The field will show at its center a blue color, about at the point where it is beginning to merge into red. A moment's consideration will indicate what this color really is. It is a mixture of all colors of the spectrum except yellow. That this is the case may be proved by analyzing the blue by means of a small direct-vision spectroscope. This will show a spectrum through which runs a dark band between the red and green, that is, where the yellow would normally appear. The blue of the wedge at this point is therefore the complement of yellow, which has been made to disappear by interference. Next focus the microscope on the wedge opposite the second line. Here the color will be nearly a sky blue, with perhaps a tinge of green. Upon analysis with the spectroscope again a dark band will be found in the yellow, this time due to interference brought about by a difference in phase of two wave-lengths for sodium light. Proceeding next to opposite the third line the color will be found to be a light green, which on analysis shows a band where yellow should occur and a perceptible shortening of the spectrum, especially by cutting off the extreme blue and violet. Opposite the fourth line the color would be a very pale green which upon analysis with the spectroscope would show two dark bands, one in the yellow and another in the blue. The pale green color is therefore due to a mixture of red, green, and violet. If, in the original experiment the wedge had been illuminated by a monochromatic blue light it would have been found at the thicker end of the wedge, where the fourth band for yellow light was located, there would have been a fifth band for the blue light. Consequently the interference color at this point of the wedge is equivalent to white light from which both yellow and blue have been subtracted. If a wedge of extra length was available for study it would have been noted that opposite the eighth band for sodium light the color showing, when the wedge is studied in the polarizing microscope, was white. This upon analysis would show a spectrum crossed by bands in the red, yellow, green, and blue. In other words, in traversing the thickness of the quartz at this point, the faster ray has gained for red seven wave-lengths over the slower ray, for yellow eight, for green nine, for blue ten. The white polarization effect seen when looking at this point with the microscope is known as white of the higher order. It is a mixture of the several primary colors of the spectrum, some portions of all of which are present and combine to give the effect of white.

It is important to study carefully the polarization colors of the quartz wedge under the microscope, using Fig. 544 as a guide. It will be noted that the colors occur in general in the following order as the thickness of the quartz increases: violet, blue, green, yellow, orange, red. This sequence of colors is repeated quite distinctly three times and then as the thicker end of the wedge is approached the colors become fainter and not so clear. This series of interference colors is divided into orders as indicated in Fig. 544. It is to be

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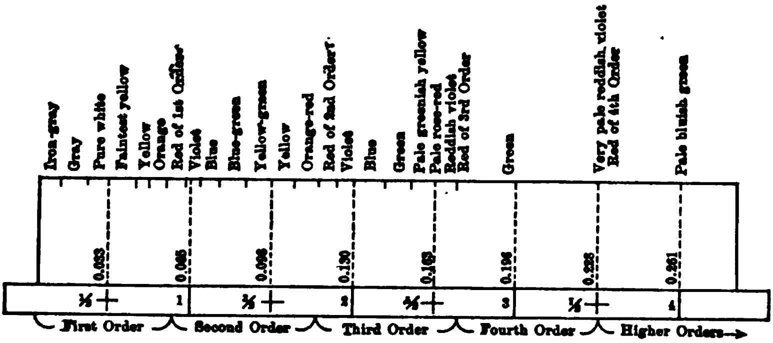

Interference Colors with Quartz Wedge

noted that at the very thin end of the wedge before any interference can have taken place the color is white. Also the thicker end of the wedge is white because here there is an overlapping of the various points of interference of the different colors. The thickness of the wedge at the different points is given in millimeters in Fig. 544.

344. Sensitive Tint. — Among the accessories of the polarizing microscope is a thin plate of gypsum mounted between two plates of glass. It is commonly marked S. T. and also with an arrow marked either X (𝔬) or Z (𝔢), indicating respectively the direction of vibration of the faster or slower ray. If this is placed on the microscope stage in the 45° position with the nicols crossed, the interference color shown is reddish violet, the same as that close to the red of the first order of the quartz wedge. It is an interesting experiment to first put a quartz wedge under the microscope and focus on the red-violet, just beyond the red of the first order and then cover it with the sensitive tint arranged in such a way that its X direction is at right angles to the X direction of the quartz wedge. The resulting color will be gray. The explanation of this is simple. Whatever gain the faster ray had made over the slower in passing through the quartz has been overcome or neutralized by passing through a layer of gypsum of opposite optical orientation and of suitable thickness to produce the same interference as the quartz. The name *Sensitive Tint* is given to this gypsum plate because a slight increase of the double refraction which it shows will give a blue color while a corresponding slight decrease will change the color to yellow. Numerous uses of the sensitive tint will be given in subsequent articles.

345. Interference Colors of Mineral Sections. — The interference colors of mineral sections depend upon three things.

1. On the strength of the birefringence of the mineral, or in other words upon the amount of double refraction that the mineral shows. The greater the birefringence the higher the order of interference color, the other influencing factors remaining constant.

2. The thickness of the section. The thicker the section the greater will be the amount of double refraction and consequently the higher the order of the interference color.

3. The crystallographic orientation of the section. This will be explained later when the optical characters of the different crystal systems are described.

346. Determination of the Order of the Interference Color of a Mineral Section. — It is often important to determine to which order (see last paragraph of Art. **343**) the interference color of a given section belongs. If, as is often the case, the section has somewhere a tapering wedge-like edge, the successive bands of color shown there can be counted and the order of the color of the surface of the section determined. In other words the order of the color can be told in the same way as upon the quartz wedge itself. If such an edge cannot be found the quartz wedge is used as described below.

Suppose a certain mineral section showed an interference color of orange-red and it was desired to ascertain whether this color belonged to the first or second order. Under the microscope with crossed nicols find a position of extinction of the section and then turn it upon the stage of the microscope through an angle of 45°. By doing this the vibration directions of the section are brought into such a position that they make angles of 45° with the vibration directions of the polarizer and analyzer. Then insert above the section and below the analyzer a quartz wedge, the optical orientation of which is known. A slot running through the microscope tube just above the objective and making an angle of 45° to the cross-hairs is provided for this purpose.

Under these conditions there are two possibilities. Either the optical orientation of the section and the quartz wedge agree; *i.e.*, the X direction of the section is parallel to the X direction of the wedge, or these two directions are at right angles to each other. The effect of the introduction of the wedge above the section will be either to increase or decrease the amount of double refraction of the light due to the mineral section. If the double refraction is increased, the optical effect will be as if the mineral section had been thickened and in this case its interference color will rise in its order. On the other hand, if the double refraction of the light is decreased by the introduction of the quartz wedge the effect will be as if the mineral section had been thinned and the interference color will fall in its order. In the first case the red interference color of the section would be changed as the wedge is pushed in, first to blue and then to green. In the second case it would change to orange, then to yellow and green. Arrange the section, therefore, so that upon the introduction of the quartz wedge the interference color will fall in its order. Then gradually continue to push in the wedge, noting the successive colors that occur as the amount of the double refraction is decreased. Finally the point will be reached where the thickness of the wedge will give practically the same amount of double refraction as the mineral section. The two having opposite optical orientations the result will be to eliminate all interference and a gray color of the first order will result. When this condition arises the quartz wedge is said to *compensate the mineral.* By noting the succession of colors that occurs until this point is reached the order of the original color of the section can be determined.

347. Determination of Strength of Birefringence. — The birefringence, or amount of double refraction, varies with different minerals. It is expressed numerically by a figure that is the difference between the greatest and least indices of refraction of a given mineral. In the case of calcite, for instance, the index of refraction for one ray is 1·486 and for the other is 1·658. The birefringence of calcite therefore equals 0·172. This is much higher than for most minerals, the strength of the birefringence of quartz being only 0·0091.

An accurate estimation of the strength of the birefringence of a mineral is to be made only by determining the greatest and least indices of refraction. An approximate determination, however, can often be made in a thin section under the microscope. The order of the interference color of a section, as stated in Art. **345**, varies with the thickness of the mineral, its crystallographic orientation and the strength of its birefringence. If the first two factors are known the birefringence can be estimated by noting the interference color of the section. Fig. 545 will aid in this determination. The thickness of the section is shown in the column at the left. The strength of the birefringence is expressed along the top and right-hand side of the figure. Suppose that a given section was 0·03 mm. in thickness and showed an orange-red interference color of the first order. By following the diagonal line that crosses the horizontal line marked 0·03 mm. at a point lying in the middle of the orange-red of the first order it will be seen that the birefringence of the mineral must be about 0·015. This method of determining birefringence is most commonly used in the case of minerals observed in rock sections. In the case of the best rock sections the thickness of the section is usually about 0·03 to 0·04 mm. The thickness of the section can also be judged from the interference color shown by some known mineral, like quartz or feldspar, which is to be observed in the section. As the strength of the birefringence of a mineral varies with its crystallographic orientation it is necessary always to look over the rock section and use in the observations that section of the mineral which shows the highest order of interference color. The birefringence of a mineral is always expressed as the maximum difference between the indices of refraction. Consequently, with a uniform thickness, such as is obtained in a rock section, that

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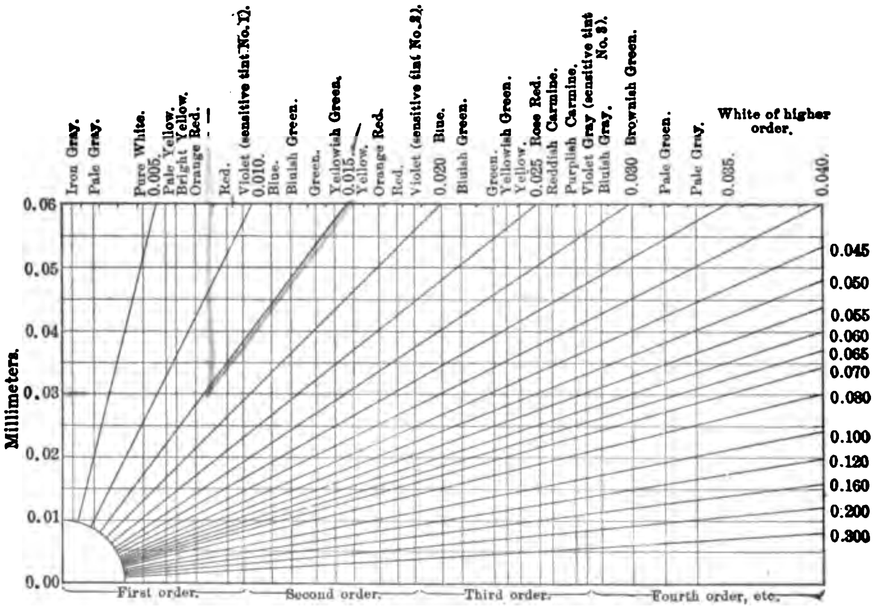

Determination of the Strength of Birefringence (after Pirsson and Robinson) section of a mineral which shows the highest order of interference color most nearly approaches the proper orientation for the maximum birefringence.

The order of the interference color of a given section is to be determined by the method of compensation as explained in Art. **346.** Special quartz wedges are made with scales upon them giving the birefringence produced by the varying thicknesses of the wedge. If such a wedge is available it is only necessary to note the birefringence corresponding to that thickness of the quartz which produced compensation. This will obviously equal the birefringence of the section being tested. For a detailed description of the various wedges and compensators used for this purpose the reader must be referred to more special text-books.*

348. Determination of the Relative Optical Character of the Extinction Directions of any Section of a Doubly Refracting Mineral. — It frequently becomes important to determine which of the two rays of light in a doubly refracting mineral is being propagated with the greater or less velocity; in other words, to determine which of the two directions of vibration corresponds to the *X* and which to the *Z* direction. Place the given section under the microscope with the nicols crossed. Find a position of extinction and then turn the section through an arc of 45° so that its vibration directions make that angle with the planes of vibration of the nicols. If the section in this position shows a strong color or white of the higher order the quartz wedge is used. The optical orientation of the wedge must be known, *i.e.*, which are its *X* and *Z* directions. The wedge is then pushed through the slot above the objective lens, the thin end of the wedge being introduced first. The vibration directions of the wedge and the section will now coincide and the effect of the gradual introduction of the wedge above the mineral will be to slowly increase or decrease the birefringence due to the section. The result will be to either raise or lower the order of the interference color obtained. If the *X* directions of the wedge and the section coincide the effect will be additive in character and the color will rise in its order. If the optical directions of the two are opposed to each other the birefringence is decreased and the color will fall. By noting which effect takes place the *X* and *Z* directions of the section are determined.

In this use of the quartz wedge the following precaution must be observed. If the section originally showed a color of the first order and the wedge was introduced in the opposed position the effect would be to cause the color to fall rapidly to gray of the first order. The optical effect of the quartz wedge would thus quickly compensate that of the section. From this point on as the quartz wedge is pushed further in, the optical effect of the wedge will more and more preponderate over that of the section and the interference colors will now appear in ascending order. Under these conditions, if the first effect of the quartz wedge was overlooked, a wrong deduction would be made. It is always best to repeat the test with the section rotated 90° from the first position. The two results should be of opposite character and so serve to confirm each other.

Frequently a thick section of a mineral will show a tapering edge somewhere which will show bands of color. When the quartz wedge is introduced above the section these color bands will move, either toward the center of the section, or go off toward the edge. When the color bands move up on the section it means that the effect of the quartz wedge is such that a thicker part of the section is now showing the same interference as a thinner part did originally. In other words, the result is as if the section had been thinned. If this is so, then the X and Z directions of the section and the wedge must be opposed to each other. On the other hand, if the color bands move off the section it means that a thinner part of the section is showing the same interference effect that a thicker portion did originally. The introduction of the quartz wedge has in effect thickened the section and therefore the similar optical directions of the two coincide. This test is particularly useful for determining the X and Z directions of deeply colored minerals, as the natural color of the mineral may, over the thicker portion of the section, completely mask the interference color.

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* See Johannsen, Manual of Petrographic Methods; Wright, The Methods of Petrographic-Microscopic Research.

If a mineral section shows an interference color of white or gray of the first order the sensitive tint will give better results than the quartz wedge. If the similar optical directions of the section and the sensitive tint coincide the effect will be to raise the color of the sensitive tint (red of the first order) to blue. On the other hand, if the optical orientations of the two are opposed the color will fall to yellow. This test can be made to advantage only when the birefringent effect of the section is small enough to just raise or lower the color of the sensitive tint respectively to blue or yellow.

349. Circularly and Elliptically Polarized Light. In the preceding articles the two interfering light-rays, after emerging from the second nicol, were assumed to be polarized in the same plane; for them the resulting phenomena as indicated are comparatively simple. If, however, two plane-polarized rays propagated in the same direction have their vibration-directions at right angles to each other, and if they differ one-quarter of a wave-length ($\frac{1}{4}\lambda$) in phase (assuming monochromatic light), then it may be shown that the composition of these two systems results in a ray of *circularly polarized* light. Briefly expressed, this is a ray that, looked at end-on, would seem to be propagated by ether-vibrations taking place in circles about the line of transmission. From the side, the onward motion would be like that of a screw, and either right-handed or left-handed.

If, again, two light-rays meet as above described, with a difference of phase differing from $\frac{1}{4}\lambda$ (but not equal to an even multiple of $\frac{1}{2}\lambda$), then the resulting composition gives rise to *elliptically polarized* light, that is, a light-ray propagated by ether-motions taking place in ellipses.

The above results are obtained most simply by passing plane-polarized light through a doubly refracting medium of the proper thickness (*e.g.*, a mica plate) which is placed with its vibration-planes inclined 45° to that of the polarizer. If the thickness is such as to give a difference in phase of $\frac{1}{4}\lambda$ or an odd multiple of this, the light which emerges is circularly polarized. If the phase differs from $\frac{1}{4}\lambda$ (but is not equal to $\frac{1}{2}\lambda$ or λ), the emergent light is elliptically polarized.

350. Rotation of Plane of Polarization. — In the case of certain doubly refracting crystallized media (as quartz), and also of certain solutions (as of sugar), it can be shown that the light is propagated by two sets of ether-vibrations which take place, not in definite transverse planes — as in plane-polarized light — but in circles; that is, each ray is circularly polarized, one being right-handed, the other left-handed. Further, of these rays, one will uniformly gain with reference to the other. The result is, that if a ray of plane-polarized light fall upon such a medium (assuming the simplest case, as of a section of quartz cut normal to the vertical crystal axis), it is found that the two rays circularly polarized within unite on emerging to a plane-polarized ray, but the plane of polarization has suffered an angular change or rotation, which may be either to the right (to one looking in the direction of the ray), when the substance is said to be *right-handed*, or to the left, when it is called *left-handed.*

This phenomenon is theoretically possible with all crystals of a given system belonging to any of the classes of lower symmetry than the normal class which show a plagiohedral development of the faces *; or, more simply, those in which the corresponding right and left (or + and −) typical forms are enantiomorphous (pp. 71, 112), as noted in the chapter on crystallography. In mineralogy, this subject is most important with the common species quartz, of the rhombohedral-trapezohedral class, and a further discussion of it is postponed to a later page (Art. **394**).

OPTICAL INSTRUMENTS AND METHODS

351. Measurement of Refractive Indices. Refractometer. — For the determination of the refractive indices of crystallized minerals various methods are employed. The most accurate results, when suitable material is at hand, may be obtained by the ordinary refractometer. This requires the observation of the angle of minimum deviation (δ) of a light-ray on passing through a prism of the given material, having a known angle (α), and with its edge cut in the proper direction. The measurements of α and δ can be made with an ordinary refractometer or with the horizontal goniometer described in Art. **231**. For the latter instrument, the collimator is made stationary, being fastened to a leg of the tripod support, but the observing telescope with the verniers moves freely. Further, for this object the graduated circle is clamped, and the screw attachments connected with the axis carrying the support, and the vernier circle and observing telescope are loosened. Light from a monochromatic source passes through an appropriate slit and an image of this is thrown by the collimator upon the prism. With a doubly refracting substance two images are yielded and the angle of minimum deviation must be measured for each; the proper direction for the edge of the prism in this case is discussed later. When α and δ are known the formula in Art. **327** is used.

352. Total Refractometer. — The principle of total reflection (Art. **323**) may also be made use of to determine the refractive index. No prism is required, but only a small fragment having a single polished surface; this may have any direction with an isometric crystal, but in other cases must have a definite orientation, as described later. A number of different instruments have been devised by means of which indices of refraction may be measured by the use of total reflection. A type widely used at present is represented in Fig. 546. This particular instrument was made by Leiss. It consists of a hemisphere of glass (H) having a high refractive index which is mounted upon a glass post through which light may be reflected from the mirror Sp. The tube *P* contains a nicol prism so that when a thin section of a mineral is placed upon the plane surface of the hemisphere it is possible to obtain its optical orientation in the same manner as with the polarizing microscope. The polished mineral surface is placed upon the plane surface of *H* with a film of some high refracting oil between them. Then a beam of light from some source of illumination, usually a monochromatic light, is reflected by means of the mirror *Bl* in such a way as to produce a total reflection shadow down on the opposite side of the hemisphere. For further details of the operation see Art. **327.** The telescope *F* is attached to the disk *V* which in turn carries a scale on its edge. The telescope is moved up or down until the line between the light and dark portions of the field lies on the cross-hairs. The angle which is read on the scale under these conditions is the desired critical angle for the combination of the glass of the hemisphere and the mineral plate. Knowing this angle and the index of refraction of the glass of the hemisphere it is possible to calculate the index of refraction of the mineral; see Art. **327.** Usually a table is furnished with the total refractometer by means of which the desired refractive index is obtained directly from the value of the measured critical angle. The post carrying the glass hemisphere may be revolved in the horizontal plane and the angle of rotation measured on the scale *K*. This permits the measurement of indices corresponding to different vibration directions in the mineral. *L* is an eye lens which in combination with the other lenses of the tube *F* makes a low power microscope, which is used in the preliminary operations in order to center the mineral plate, etc. In the tube *A* is an iris diaphragm and usually a small nicol prism that may be pushed in or out of the tube.

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* Of the thirty-two possible classes among crystals, the following eleven may be characterized by circular polarization: Class 4, p. 71; 5, p. 72; 11 and 12, p. 89; 17, p. 102; 22, p. 112; 23 and 24, p. 114; 27, p. 128; 29, p. 138; 32, p. 147.

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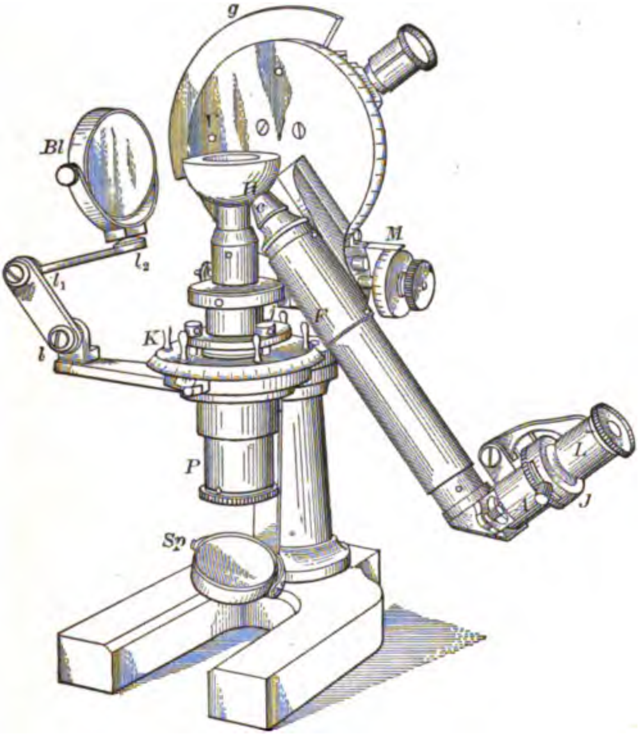

Total Refractometer

Fig. 547 represents a small total refractometer devised by G. F. H. Smith which depends upon the same principle. The mineral plate is placed upon the glass surface shown on the top of the instrument. The instrument is so held that light enters at the forward end, and the totally reflected light is sent by means of an inclined mirror to the eyepiece. A scale is placed in the instrument in such a way that the boundary between the light and dark areas is seen superimposed upon it and so yields directly the value of the refractive index. For rapid and approximate determinations this instrument is very useful.

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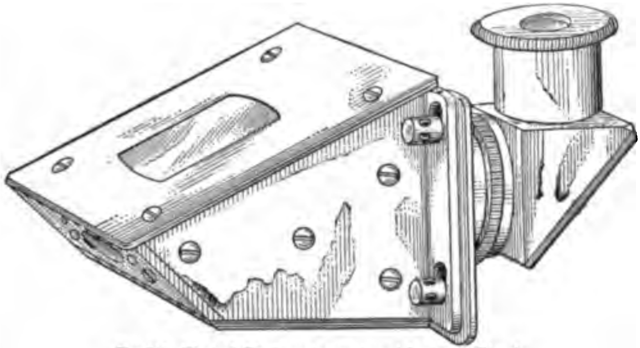

Smith Total Refractometer (Actual Size)

353. Tourmaline Tongs. — A very simple form of polariscope for converging light is shown in Fig. 548; it is convenient in use, but of limited application. Here the polarizer and analyzer are two tourmaline plates such as were described in Art. **340.** They are mounted in pieces of cork and held in a kind of wire pincers. The object to be examined is placed between them and supported there by the spring in the wire. In use they are held close to the eye, and in this position the crystal section is viewed in *converging* polarized light, with the result of showing (under proper conditions) the axial interference-figures (Arts. **389** and **407**).

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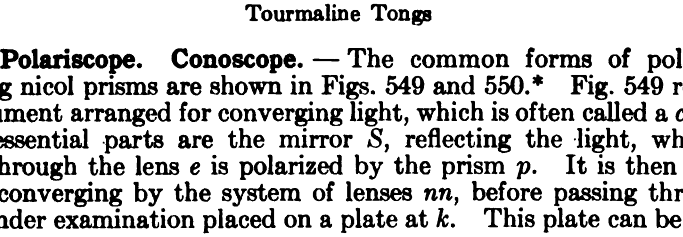

Tourmaline Tongs

354. Polariscope. Conoscope. — The common forms of polariscopes employing nicol prisms are shown in Figs. 549 and 550.* Fig. 549 represents the instrument arranged for converging light, which is often called a *conoscope.* The essential parts are the mirror S, reflecting the light, which after passing through the lens e is polarized by the prism p. It is then rendered strongly converging by the system of lenses nn, before passing through the section under examination placed on a plate at k. This plate can be revolved through any angle desired, measured on its circumference. The upper tube contains the converging system *oo*, the lens *t*, and the analyzing prism *q*. The arrangements for lowering or raising the tubes need no explanation, nor indeed the special devices for setting the vibration-planes of the nicols at right angles to each other.

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* These figures are taken from the catalogue of Fuess.

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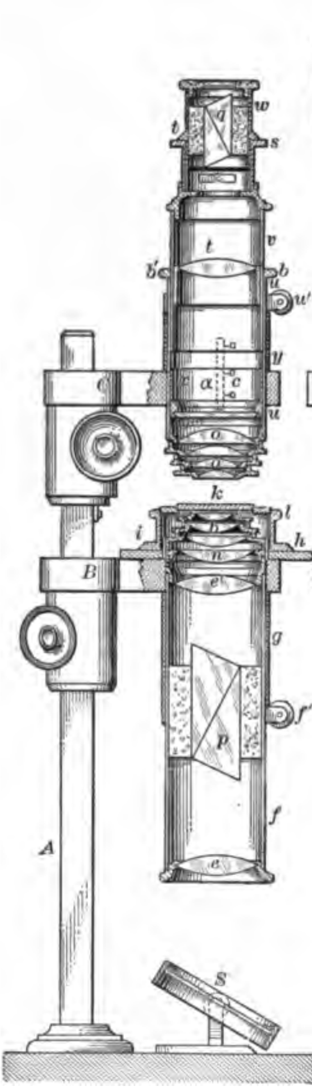

Conoscope

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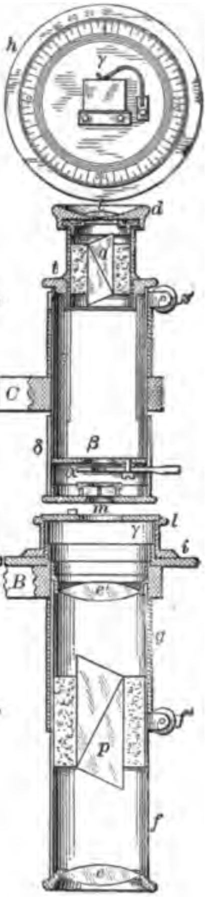

Polariscope

The accompanying tube (Fig. 550) shows the arrangement for observations in parallel light, the converging lenses having been removed.

Fig. 551 represents in cross-section a simple, inexpensive but quite efficient form of polariscope. The polarizing device, *P*, is in the form of two or three thin glass sheets, the back of the bottom one being blackened. These glass plates are set at the appropriate angle to secure the maximum amount of polarization of the light reflected from them up through the opening in the stage *K*. M represents an adjustable mirror by means of which light is reflected upon P. The analyzer, A, is a small nicol prism which is held over the opening in the stage by means of the standard S. A double series of lenses may be placed upon the stage of the instrument and so convert it into a conoscope.

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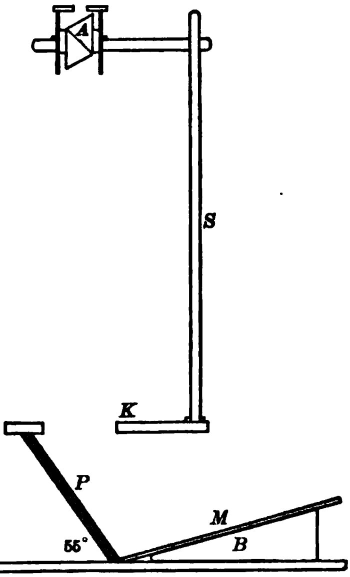

Polariscope (¼ natural size)

355. Polarization-Microscope. — The investigation of the form and optical properties of minerals when in microscopic form has been much facilitated by the use of microscopes * specially adapted for this purpose. First arranged with reference to the special study of minerals as seen in thin sections of rocks, they have now been so elaborated as largely to take the place of the older optical instruments. They not only allow of the determination of the optical properties of minerals with greater facility, but are applicable to many cases where the crystals in hand are far too small for other means.

A highly serviceable microscope is the Laboratory Model made by the Bausch and Lomb Optical Co., and illustrated in Fig. 552. The essential arrangements of this instrument are as follows: The eyepiece at *A*, which is removable, contains the cross-hairs with an eye lens adjustable for focusing upon them. At *B* is a Bertrand lens that slides in and out of the tube, with an iris diaphragm immediately above it. At *C* is the analyzer box which slides in and out of the body tube. This prism may be revolved through a quarter turn. *D* is a slot in the microscope tube with a dust-proof shutter for the introduction of various accessories, such as the quartz wedge, etc. At *E* is the nosepiece which can be centered by the two screws which work at right angles in the *N* and *E* positions. The objective *F* is held in place by a spring clamp and is quickly detached. The stage, *G*, revolves and carries a scale graduated into degrees, the attached vernier permitting the reading of angles to one-tenth degree. The substage at *H* carries condensing lenses, iris diaphragm and the polarizing prism. It can be moved upward and downward by means of a screw-head and when at its lowest point can be sprung to one side, out of the optical axis. The mirror at *I* is adjustable and has both a plane and concave surface. The coarse focusing adjustment is at *J*, while the milled head at *K* provides a fine adjustment by means of which a vertical movement of 0·0005 mm. can be read.

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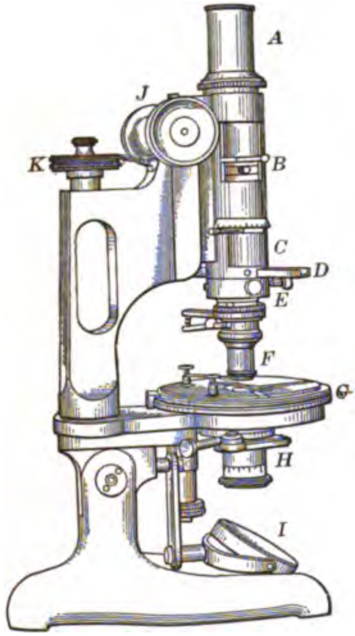
* For detailed descriptions of the polarizing microscope and its accessories see Johannsen, Manual of Petrographic Methods; Wright, The Methods of Petrographic Research; etc.

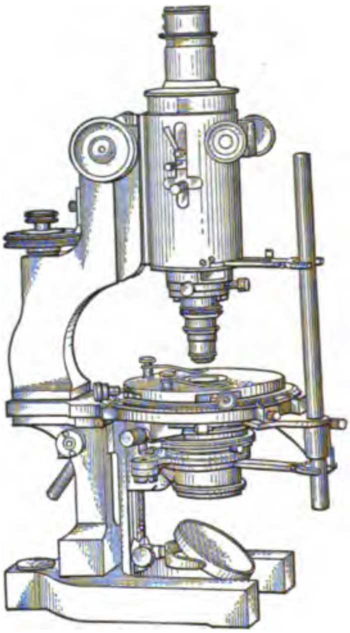
356. The Research Model of the Bausch and Lomb microscope is illustrated in Fig. 553. This instrument is patterned after one described by Wright to whose papers reference is made for a more detailed account. The outstanding features of the instrument may be briefly summarized as follows: It has a large body-tube within which are always contained the analyzer and the Bertrand lens, both when they lie in or outside the optical axis of the microscope. The two nicols may be connected by means of the upright bar and rotated simultaneously through an arc of 90°. This enables the measurement of extinction angles, etc., to be made without the necessity of revolving the stage and the consequent difficulty in keeping the mineral grain under observation exactly centered in the field. This bar carries verniers that lie against the scale engraved upon the stage so that the angle of rotation of the nicols can be accurately measured. The polarizing prism can be entirely removed from the optical axis. A revolvable carrier for a sensitive plate is attached to the iris diaphragm mount of the substage.

552



Petrographical Microscope
(Laboratory Model, Bausch and
Lomb, ¼ actual size)

553



Petrographical Microscope
(Research Model, Bausch and
Lomb ¼ actual size)

GENERAL OPTICAL CHARACTERS OF MINERALS

357. There are certain characteristics belonging to all minerals alike, crystallized and non-crystallized, in their relation to light. These are:

1. Diaphaneity: depending on the relative quantity of light transmitted.

2. COLOR: depending on the kind of light reflected or transmitted, as determined by the selective absorption.

3. LUSTER: depending on the power and manner of reflecting light.

1. DIAPHANEITY

358. Degrees of Transparency. — The amount of light transmitted by a solid varies in intensity, or, in other words, more or less light may be *absorbed* in the passage through the given substance (see Art. **330**). The amount of absorption is a minimum in a transparent solid, as ice, while it is greatest in one which is opaque, as iron. The following terms are adopted to express the different degrees in the power of transmitting light:

Transparent: when the outline of an object seen through the mineral is perfectly distinct.

Subtransparent, or *semi-transparent:* when objects are seen, but the outlines are not distinct.

Translucent: when light is transmitted, but objects are not seen.

Subtranslucent: when merely the edges transmit light or are translucent.

When no light is transmitted, even on the thin edges of small splinters, the mineral is said to be *opaque*. This is properly only a *relative* term, since no substance fails to transmit some light, if made sufficiently thin. Magnetite is translucent in the Pennsbury mica. Even gold may be beaten out so thin as to be translucent, in which case it transmits a greenish light.

The property of diaphaneity occurs in the mineral kingdom, from nearly perfect opacity to transparency, and many minerals present, in their numerous varieties, nearly all the different degrees.

2. COLOR

359. Nature of Color. — As briefly explained in Art. **314**, the sensation of color depends, in the case of monochromatic light, solely upon the length of the waves of light which meet the eye. If the light consists of various wave-lengths, it is to the combined effect of these that the sensation of color is due.

Further, since the light ordinarily employed is essentially white light, that is, consists of all the wave-lengths corresponding to the successive colors of the spectrum, the color of a body depends upon the selective absorption (see Art. **330**) which it exerts upon the light transmitted or reflected by it. A yellow mineral, for instance, absorbs all the waves of the spectrum with the exception of those which together give the sensation of yellow. In general, the color which the eye perceives is the result of the mixture of those waves which are not absorbed.

360. Streak. — The color of the powder of a mineral as obtained by scratching the surface of the mineral with a knife or file, or, still better, if the mineral is not too hard, by rubbing it on an unglazed porcelain surface, is called the *streak*. The streak is often a very important quality in distinguishing minerals. This is especially true with minerals having a metallic luster, as defined in Art. **364**.

361. Dichroism; Pleochroism. — The selective absorption, to which the color of a mineral is due, more especially by transmitted light, often varies with the crystallographic direction in which the light passes through the mineral. It is hence one of the special optical characters depending upon the crystallization, which are discussed later. Here belong *dichroism* or *pleochroism*, the property of exhibiting different colors in different crystallographic directions by transmitted light. This subject is explained further in Arts. **398** and **411**.

362. Varieties of Color. — The following eight colors were selected by Werner as fundamental, to facilitate the employment of this character in the description of minerals: *white, gray, black, blue, green, yellow, red,* and *brown.*

(*a*) The varieties of METALLIC COLORS recognized are as follows:

1. *Copper-red:* native copper. — 2. *Bronze-yellow:* pyrrhotite. — 3. *Brass-yellow:* chalcopyrite. — 4. *Gold-yellow:* native gold. – 5. *Silver-white:* native silver, less distinct in arsenopyrite. — 6. *Tin-white:* mercury; cobaltite. — 7. *Lead-gray:* galena, molybdenite. — 8. *Steel-gray:* nearly the color of fine-grained steel on a recent fracture; native platinum, and palladium.

(*b*) The following are the varieties of NON-METALLIC COLORS:

A. WHITE. 1. *Snow-white:* Carrara marble. — 2. *Reddish white,* 3. *Yellowish white* and 4. *Grayish white:* all illustrated by some varieties of calcite and quartz. — 5. *Greenish white:* talc. — 6. *Milk white:* white, slightly bluish; some chalcedony.

B. GRAY. 1. *Bluish gray:* gray, inclining to dirty blue. — 2. *Pearl-gray:* gray, mixed with red and blue; cerargyrite. — 3. *Smoke-gray:* gray, with some brown; flint. — 4. *Greenish gray:* gray, with some green; cat's-eye; some varieties of talc. — 5. *Yellowish gray:* some varieties of compact limestone. — 6. *Ash-gray:* the purest gray color; zoisite.

C. BLACK. 1. *Grayish black:* black, mixed with gray (without green, brown, or blue tints); basalt; Lydian stone. — 2. *Velvet-black:* pure black; obsidian, black tourmaline. — 3. *Greenish black:* augite. — 4. *Brownish black:* brown coal, lignite. — 5. *Bluish black:* black cobalt.

D. BLUE. 1. *Blackish blue:* dark varieties of azurite. — 2. *Azure-blue:* a clear shade of bright blue; pale varieties of azurite, bright varieties of lazulite. — 3. *Violet-blue:* blue, mixed with red; amethyst, fluorite. — 4. *Lavender-blue:* blue, with some red and much gray. — 5. *Prussian-blue,* or Berlin blue: pure blue; sapphire, cyanite. — 6. *Smalt-blue:* some varieties of gypsum. — 7. *Indigo-blue:* blue, with black and green; blue tourmaline. — 8. *Sky-blue:* pale blue, with a little green; it is called mountain-blue by painters.

E. GREEN. 1. *Verdigris-green:* green, inclining to blue; some feldspar (amazon-stone). – 2. *Celandine-green:* green, with blue and gray; some varieties of talc and beryl. It is the color of the leaves of the celandine. — 3. *Mountain-green:* green, with much blue; beryl. — 4. *Leek-green:* green, with some brown; the color of leaves of garlic; distinctly seen in prase, a variety of quartz. — 5. *Emerald-green:* pure deep green; emerald. — 6. *Apple-green:* light green with some yellow; chrysoprase. — 7. *Grass-green:* bright green, with more yellow; green diallage. — 8. *Pistachio-green:* yellowish green, with some brown; epidote. — 9. *Asparagus-green:* pale green, with much yellow; asparagus stone (apatite). — 10. *Blackish green:* serpentine. — 11. *Olive-green:* dark green, with much brown and yellow; chrysolite. — 12. *Oil-green:* the color of olive-oil; beryl, pitchstone. — 13. *Siskin-green:* light green, much inclining to yellow; uranite.

F. YELLOW. 1. *Sulphur-yellow:* sulphur. — 2. *Straw-yellow:* pale yellow; topaz. — 3. *Wax-yellow:* grayish yellow with some brown; sphalerite, opal. — 4. *Honey-yellow:* yellow, with some red and brown; calcite. — 5. *Lemon-yellow:* sulphur, orpiment. — 6. *Ocher-yellow:* yellow, with brown; yellow ocher. — 7. *Wine-yellow:* topaz and fluorite. — 8. *Cream-yellow:* some varieties of kaolinite. — 9. *Orange-yellow:* orpiment.

G. RED. 1. *Aurora-red:* red, with much yellow; some realgar. — 2. *Hyacinth-red:* red, with yellow and some brown; hyacinth garnet. — 3. *Brick-red:* polyhalite, some jasper. — 4. *Scarlet-red:* bright red, with a tinge of yellow; cinnabar. — 5. *Blood-red:* dark red, with some yellow; pyrope. — 6. *Flesh-red:* feldspar. — 7. *Carmine-red:* pure red; ruby sapphire. — 8. *Rose-red:* rose quartz. — 9. *Crimson-red:* ruby. — 10. *Peachblossom-red:* red, with white and gray; lepidolite. — 11. *Columbine-red:* deep red, with some blue; garnet. — 12. *Cherry-red:* dark red, with some blue and brown; spinel, some jasper. — 13. *Brownish-red:* jasper, limonite.

H. BROWN. 1. *Reddish brown:* garnet, zircon. — 2. *Clove-brown:* brown, with red and some blue; axinite. — 3. *Hair-brown:* wood-opal. — 4. *Broccoli-brown:* brown, with blue, red, and gray; zircon. — 5. *Chestnut-brown:* pure brown. — 6. *Yellowish brown:* jasper. — 7. *Pinchbeck-brown:* yellowish brown, with a metallic or metallic-pearly luster; several varieties of talc, bronzite. — 8. *Wood-brown:* color of old wood nearly rotten; some specimens of asbestus. — 9. *Liver-brown:* brown, with some gray and green; jasper. — 10. *Blackish brown:* bituminous coal, brown coal.

3. LUSTER

363. Nature of Luster. — The luster of minerals varies with the nature of their surfaces. A variation in the quantity of light reflected produces different degrees of intensity of luster; a variation in the nature of the reflecting surface produces different kinds of luster.

364. Kinds of Luster. — The kinds of luster recognized are as follows:

1. METALLIC: the luster of the metals, as of gold, copper, iron, tin.

In general, a mineral is not said to have metallic luster unless it is opaque in the mineralogical sense, that is, it transmits no light on the edges of thin splinters. Some minerals have varieties with metallic and others with non-metallic luster; this is true of hematite.

Imperfect metallic luster is expressed by the term *sub-metallic,* as illustrated by columbite, wolframite. Other kinds of luster are described briefly as NON-METALLIC.

2. NON-METALLIC. *A. Adamantine:* the luster of the diamond. When also sub-metallic, it is termed *metallic-adamantine,* as cerussite, pyrargyrite.

Adamantine luster belongs to substances of high refractive index. This may be connected with their relatively great density (and hardness), as with the diamond, also corundum, etc.; or because they contain heavy molecules, thus most compounds of lead, not metallic in luster, have a high refractive index and an adamantine luster.

B. Vitreous: the luster of broken glass. An imperfectly vitreous luster is termed *sub-vitreous.* The vitreous and sub-vitreous lusters are the most common in the mineral kingdom. Quartz possesses the former in an eminent degree; calcite, often the latter.

C. Resinous: luster of the yellow resins, as opal, and some yellow varieties of sphalerite.

D. Greasy: luster of oily glass. This is near resinous luster, but is often quite distinct, as nephelite.

E. Pearly: like pearl, as talc, brucite, stilbite, etc. When united with sub-metallic, as in hypersthene, the term *metallic-pearly* is used.

Pearly luster belongs to the light reflected from a pile of thin glass-plates; similarly it is exhibited by minerals, which, having a perfect cleavage, may be partially separated into successive plates, as on the basal plane of apophyllite. It is also shown for a like reason by foliated minerals, as talc and brucite.

F. Silky: like silk; it is the result of a fibrous structure. Ex. fibrous calcite, fibrous gypsum.

The different degrees and kinds of luster are often exhibited differently by unlike faces of the same crystal, but always similarly by like faces. For example, the basal plane of apophyllite has a pearly luster wanting in the prismatic faces, which have a vitreous luster.

As shown by Haidinger, only vitreous, adamantine, and metallic luster belong to faces perfectly smooth and pure. In the first, the refractive index of the mineral is 1·3–1·8; in the second, 1·9–2·5; in the third, about 2·5. The true difference between metallic and vitreous luster is due to the effect which the different surfaces have upon the reflected light; in general, the luster is produced by the union of two simultaneous impressions made upon the eye. If the light reflected from a metallic surface be examined by a nicol prism (or the dichroscope of Haidinger, Art. 393), it will be found that both rays, that vibrating in the plane of incidence and that whose vibrations are normal to it, are alike, each having the color of the material, only differing a little in brilliancy; on the contrary, of the light reflected by a vitreous substance, those rays whose vibrations are at right angles to the plane of incidence are more or less polarized, and are colorless, while those whose vibrations are in this plane, having penetrated somewhat into the medium and suffered some absorption, show the color of the substance itself. A plate of red glass thus examined will show a colorless and a red image. Adamantine luster occupies a position between the others.

365. Degrees of Luster. — The *degrees of intensity* of luster are classified as follows:

1. *Splendent:* reflecting with brilliancy and giving well-defined images, as hematite, cassiterite.
2. *Shining:* producing an image by reflection, but not one well-defined, as celestite.
3. *Glistening:* affording a general reflection from the surface, but no image, as talc, chalcopyrite.
4. *Glimmering:* affording imperfect reflection, and apparently from points over the surface, as flint, chalcedony.

A mineral is said to be *dull* when there is a total absence of luster, as chalk, the ochers, kaolin.

366. Play of Colors. Opalescence. Iridescence. — The term *play of colors* is used to describe the appearance of several prismatic colors in rapid succession on turning the mineral. This property belongs in perfection to the diamond, in which it is due to its high dispersive power. It is also observed in precious opal, where it is explained on the principle of interference; in this case it is most brilliant by candle-light.

The expression *change of colors* is used when each particular color appears to pervade a larger space than in the play of colors and the succession produced by turning the mineral is less rapid. This is shown in labradorite, as explained under that species.

Opalescence is a milky or pearly reflection from the interior of a specimen. Observed in some opal, and in cat's-eye.

Iridescence means the exhibition of prismatic colors in the interior or on the surface of a mineral. The phenomena of the play of colors, iridescence, etc., are sometimes to be explained by the presence of minute foreign crystals, in parallel positions; more generally, however, they are caused by the presence of fine cleavage-lamellæ, in the light reflected from which interference takes place, analogous to the well-known Newton's rings (see Art. 336).

367. Tarnish. — A metallic surface is tarnished when its color differs from that obtained by fracture, as is the case with specimens of bornite. A surface possesses the *steel tarnish* when it presents the superficial blue color of tempered steel, as columbite. The tarnish is *irised* when it exhibits fixed prismatic colors, as is common with the hematite of Elba. These tarnish and iris colors of minerals are owing to a thin surface or film, proceeding from different sources, either from a change in the surface of the mineral or from foreign incrustation; hydrated iron oxide is one of the most common sources of it and produces the colors on anthracite and hematite.

368. Asterism. — This name is given to the peculiar star-like rays of light observed in certain directions in some minerals. This is seen by reflected light in the form of a six-rayed star in sapphire, and is also well shown by transmitted light (as of a small flame) with the phlogopite mica from South Burgess, Canada. In the former case it is explained by the presence of thin twinning-lamellæ symmetrically arranged. In the other case it is due to the presence of minute inclosed crystals, also symmetrically arranged, which are probably rutile or tourmaline in most cases. Crystalline faces which have been artificially etched also sometimes exhibit asterism. The peculiar light-figures sometimes observed in reflected light on the faces of crystals, either natural or etched, are of similar nature.

369. Schillerization. — The general term *schiller* is applied to the peculiar luster, sometimes nearly metallic, observed in definite directions in certain minerals, as conspicuously in schiller-spar (an altered variety of bronzite), also in diallage, hypersthene, sunstone, and others. It is explained by the reflection either from minute inclosed plates in parallel position or from the surfaces of minute cavities (negative crystals) having a common orientation. In many cases it is due to alteration which has developed these bodies (or the cavities) in the direction of solution-planes (see Art. 285). The process by which it has been produced is then called *schillerization.*

370. Fluorescence. — The emission of light from within a substance while it is being exposed to direct radiation, or in certain cases to an electrical discharge in a vacuum tube, is called *fluorescence.* It is best exhibited by fluorite, from which the phenomenon gained its name. Thus, if a beam of white light be passed through a cube of colorless fluorite a delicate violet color is called out in its path. This effect is chiefly due to the action of the ultra-violet rays, and is connected with a change of refrangibility in the transmitted light.

The electrical discharge from the negative pole of a vacuum tube calls out a brilliant fluorescence not only with the diamond, the ruby, and many gems, but also with calcite and other minerals. Such substances may continue to emit light, or *phosphoresce,* after the discharge ceases.

371. Phosphorescence. — The *continued* emission of light by a substance (not incandescent) produced especially after heating, exposure to light or to an electrical discharge, is called *phosphorescence.*

Fluorite becomes highly phosphorescent after being heated to about 150° C. Different varieties give off light of different colors; the *chlorophane* variety, an emerald-green light; others purple, blue, and reddish tints. This phosphorescence may be observed in a dark place by subjecting the pulverized mineral to a heat below redness. It may even be produced by a sharp blow with a hammer. Some varieties of white limestone or marble, after slight heating, emit a yellow light; so also tremolite, danburite, and other species.

The X-ray and ultra-violet light will produce phosphorescence in willemite, kunzite, and some diamonds. The fact that willemite glows when exposed to ultra-violet light is made use of in testing the residues from a willemite ore to make certain the separation has been complete. Radium emanations cause certain minerals to phosphoresce, as willemite and wurtzite.

Exposure to the light of the sun produces very apparent phosphorescence with many diamonds, but some specimens seem to be destitute of this power. This property is most striking after exposure to the blue rays of the spectrum, while in the red rays it is rapidly lost. A mixture of calcium sulphide and bismuth will phosphoresce for a considerable period after being exposed to sunlight.

SPECIAL OPTICAL CHARACTERS BELONGING TO CRYSTALS OF THE DIFFERENT SYSTEMS

372. All crystallized minerals may be grouped into three grand classes, which are distinguished by their physical properties, as well as their geometrical form. These three classes are as follows:

A. *Isometric class*, embracing crystals of the isometric system, which are referred to three equal rectangular axes.

B. *Isodiametric class*, embracing crystals of the tetragonal and hexagonal systems, referred to two, or three, equal horizontal axes and a third, or fourth, axis unequal to them at right angles to their plane. Crystals of this class have a fixed principal axis of crystallographic symmetry.

C. *Anisometric class*, embracing the crystals of the orthorhombic, monoclinic, and triclinic systems, referred to three unequal axes. Crystals of this class are without a fixed axis of crystallographic symmetry.

373. Isotropic Crystals. — Of the three classes, the ISOMETRIC CLASS includes all crystals which, with respect to light and related phenomena involving the ether, are *isotropic* (from the Greek, signifying *equal turning*); that is, those which have like optical properties in all directions. Their distinguishing characteristic is that light travels through them with equal velocity in all directions, provided their molecular equilibrium is not disturbed by external pressure or internal strain. If it be imagined therefore that light starts from a point within an isotropic medium at a given moment of time the resulting wave surface will be a sphere.

It must be emphasized here, however, that such a crystal is *not* isotropic with reference to those characters which depend directly upon the molecular structure alone, as cohesion and elasticity. (See Art. **275.**)

Further, amorphous bodies, as glass and opal, which are destitute of any orientated molecular structure — that is, those in which all directions are sensibly the same — are also isotropic, and not only with reference to light, but also as regards their strictly molecular properties.

374. Anisotropic Crystals; Uniaxial and Biaxal. — Crystals of the ISODIAMETRIC and ANISOMETRIC CLASSES, on the other hand, are in distinction *anisotropic* (from the Greek, signifying *unequal turning*). Their optical properties are in general unlike in different directions, or, more particularly, the velocity with which light is propagated varies with the direction.

Further, in crystals of the isodiametric class that variable property of the light-ether upon which the velocity of propagation depends remains constant for all directions which are normal to, or, again, for all those equally inclined to, the vertical crystallographic axis. In the direction of this axis there is no double refraction; it is hence called the *optic axis*, and the crystals of this class are said to be *uniaxial.*

Crystals of the third or anisometric class have more complex optical relations requiring special explanation, but in general it may be stated that in them there are always two directions analogous in character to the single optic axis spoken of above; hence, these crystals are said to be optically *biaxial.*

A. ISOMETRIC CRYSTALS

375. It has been stated that crystals of the isometric system are optically *isotropic*, and hence light travels with the same velocity in every direction in them. Light can, therefore, suffer only single refraction in passing into an isotropic medium; or, in other words, there can be but one value of the refractive index for a given wave-length. If this be represented by n, while V is the velocity of light in air and v that in the given medium, then

$$n = \frac{V}{v}, \quad \text{or} \quad v = \frac{V}{n}.$$

The wave-front for light-waves propagated from any point within such an isotropic medium is, as already stated, a sphere. The sphere, therefore, may be taken to represent the optical properties of an isotropic medium. Sections of a sphere normal to any diameter will always be circles. These circular sections with like radii in all directions correspond to the fact that the optical character of an isotropic substance is the same in all directions normal to the line of light propagation. Or, in other words, light vibrations may take place in any direction normal to the direction of transmission; *i.e.*, the light is not polarized. Further its velocity remains uniform no matter what may be the direction of its vibration.

This statement holds true of all the classes of isometric crystals. In other words, a crystal of maximum symmetry, as fluorite, and one having the restricted symmetry characteristic of the tetrahedral or pyritohedral divisions, have alike the same isotropic character. Two of the classes, however, namely, the plagiohedral and the tetartohedral classes, differ in this particular: that crystals belonging to them may exhibit what has already been defined (Art. **350**) as circular polarization.

376. Behavior of Sections of Isometric Crystals in Polarized Light. — In consequence of their isotropic character, isometric crystals exhibit no special phenomena in polarized light. As a section of an isotropic substance (isometric crystal or some amorphous material) has no polarizing or doubly refracting effect upon light it does not change at all the character of light that enters it from the polarizer of a polariscope. Therefore thin sections of isotropic media when examined in a polariscope or polarizing microscope with the nicols crossed will appear dark in all positions. In other words, they are always extinguished. Further, when a colored mineral is examined without the analyzer there will be no change in its color when the section is revolved with the stage of the microscope. Some anomalies are mentioned on a later page, (Art. **429**).

The single refractive index of an isotropic substance may be determined by means of a prism (see Art. **327**) with its edge cut in any direction whatever.

B. UNIAXIAL CRYSTALS

General Optical Relations

377. The crystallographic and optical relations of crystals belonging to crystals of the tetragonal and hexagonal systems have already been briefly summarized (Art. **374**); it now remains to develop their optical characters more fully. This can be done most simply by making frequent use of the familiar conception of a light-ray to represent the character and motion of the light-wave.

378. Behavior of Light in Uniaxial Minerals. — Light entering a uniaxial mineral is in general broken up into two rays which are polarized in planes perpendicular to each other and which travel with different velocities and therefore have different indices of refraction. One of the two rays derived from a single incident ray always vibrates in the plane of the horizontal crystallographic axes. The other ray vibrates at right angles to the first and always in a vertical plane that includes the vertical crystallographic axis. The optical character of a uniaxial mineral is uniform for all directions lying in the horizontal crystallographic plane and therefore the ray whose vibrations lie in this plane will have uniform velocity no matter what its direction of transmission. This ray will therefore have a single and constant index of refraction, commonly designated by ω. Since this ray follows the usual law as to the constant ratio between the sines of the angles of incidence and refraction and in general behaves in an ordinary way it is called the *ordinary ray*. The ray which vibrates in a plane that includes the vertical crystallographic axis will have the direction of its vibration constantly changing as the direction of its path through the crystal changes and its velocity will correspondingly vary. Its index of refraction will therefore depend upon the direction of its propagation and it will not in general obey the usual sine law. This ray is therefore called the *extraordinary ray*.

When light travels in a uniaxial mineral in a direction parallel to the vertical crystallographic axis, since all its vibrations must take place in the horizontal plane, it behaves wholly as the ordinary ray with a single velocity and refractive index. There can be no double refraction of light, therefore, along this direction and in this case the mineral will behave like an isotropic substance. This direction of no double refraction, coincident with the vertical crystal axis, is known as the *optic axis* and as there is only one such direction in this optical group the latter is called *uniaxial*. As soon as the direction of transmission becomes inclined to the vertical crystal axis the light is doubly refracted and as the inclination increases the direction of vibration of the light of the extraordinary ray departs more and more from the plane of vibration of the ordinary ray with a corresponding change in its velocity and refractive index. The difference between the refractive indices of the two rays becomes a maximum when the light passes through the mineral in a horizontal direction with the direction of vibration of the extraordinary ray parallel to the vertical crystal axis — or in other words as divergent as possible from the horizontal plane. The value of the refractive index of the extraordinary ray when at its maximum difference from the constant index of the ordinary ray is the one always quoted and is indicated by ϵ. These two indices, ω and ϵ, are called the *principal indices* of a uniaxial crystal. A *principal section* of a uniaxial crystal is a section passing through the vertical axis.

379. Positive and Negative Crystals. — Uniaxial crystals are divided into two classes, depending upon whether the velocity of the extraordinary ray is greater or less than that of the ordinary ray. Those in which the refractive index of the ordinary ray, ω, is less than that of the extraordinary ray, ϵ ($\omega < \epsilon$), are called *positive*. This is illustrated by quartz for which (for yellow sodium light):

$$\omega = 1{\cdot}544. \qquad \epsilon = 1{\cdot}553.$$

On the other hand, if ϵ is less than ω ($\epsilon < \omega$), the crystal is said to be *negative*.* Calcite is an example for which (for sodium light)

$$\omega = 1{\cdot}658. \qquad \epsilon = 1{\cdot}486.$$

Other examples are given later (Art. **383**).

380. Determination of the Refractive Indices in Uniaxial Crystals. — The indices of refraction of uniaxial minerals are measured in much the same way as in the case of isotropic substances. With uniaxial crystals, however, the prism or plate used must have a definite crystallographic orientation. If a prism is employed its edge should be parallel to the optic axis, or in other words parallel to the vertical crystal axis of the mineral. When such a prism is examined on the refractometer two refracted rays are seen, the angles of refraction of which can be measured by either the method of minimum deviation or perpendicular incidence as described in Art. **327.** The two rays are polarized, the ordinary ray vibrating in the horizontal plane and the extraordinary ray vibrating in the vertical plane, *i.e.*, parallel to the edge of the prism. The plane of vibration of each ray must be determined by the use of a nicol prism held in front of the eyepiece of the refractometer. When the plane of the nicol is horizontal the image belonging to the ordinary ray will be visible and when the plane of the nicol is vertical only that of the extraordinary ray will appear. In this way the indices of the two rays are determined and the positive or negative character of the mineral is established. It is possible to obtain these measurements in prisms with different crystallographic orientation but the difficulties attending their preparation are so great that such prisms are very seldom used.

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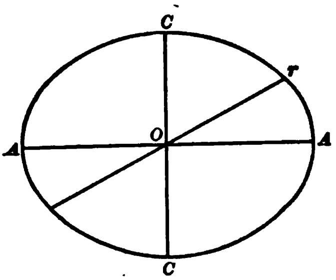
* It will assist in remembering these relations to note that the first vowel in the words positive and negative agrees with the symbol used for the smaller index of refraction in each case.

If the method of total reflection is used a single plate will suffice, provided it lies either in the prism zone of the crystal, or is parallel to the basal plane. In each case two shadows will be observed, corresponding in their position to the angles of total reflection of the two rays. When the plate is cut parallel to a face in the prism zone one of these shadows, that belonging to the ordinary ray, will remain stationary as the plate is revolved on the hemisphere of the total refractometer while the shadow of the extraordinary ray will vary from being coincident with that of the ordinary ray to a certain maximum divergence from that position. This maximum difference in position, which may yield a greater or less angle than that of the ordinary ray, depending upon the optical character of the mineral, is the angle corresponding to the true value of the refractive index of the extraordinary ray. There will be two positions at 180° apart during the complete revolution of the section at which this value may be measured. If the plate was cut parallel to the basal plane of the crystal the two shadows would both be stationary during such a revolution and the value of the angle for both rays can be measured in any position of the plate.

381. Wave-surface. — Remembering that the velocity of light-propagation is always inversely proportional to the corresponding refractive index, it is obvious that the velocity of the ordinary ray for all directions in a uniaxial crystal must be the same, being uniformly proportional to $\frac{1}{\omega}$. In other words, supposing light originates at a point within a uniaxial crystal the ordinary ray would travel out in all directions with uniform velocity and its wave-front would form a sphere.

For the extraordinary ray, however, the velocity varies with the direction, being proportional to $\frac{1}{\epsilon}$ in a horizontal direction and becoming sensibly equal to $\frac{1}{\omega}$ when nearly coincident with the direction of the vertical axis. The law of the varying change of velocity between these values, $\frac{1}{\omega}$ and $\frac{1}{\epsilon}$, is given by an ellipse whose axes (*OC*, *OA*, Figs. 554, 555) are respectively proportional to the above values.

554



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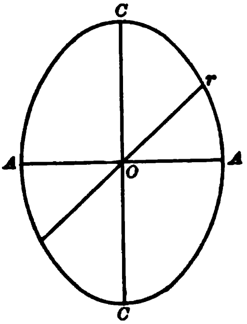
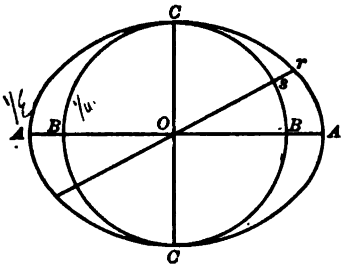


$$OC : OA = \frac{1}{\omega} : \frac{1}{\epsilon} = \epsilon : \omega.$$

The wave-front of the extraordinary ray is then a spheroid, or an ellipsoid of revolution whose axis coincides with the vertical crystallographic axis, that is, the optic axis. In the direction of the vertical axis it is obvious that the wave-fronts of the ordinary and extraordinary rays will coincide.

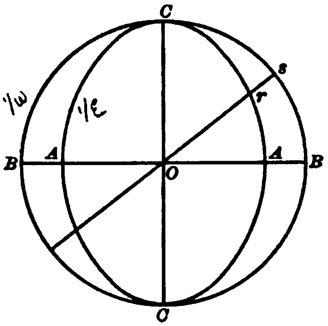
Figures 556 and 557 represent vertical sections of the combined wave-surfaces for both rays. Fig. 556 gives that for a *negative* crystal like calcite ($\epsilon < \omega$), the ellipsoidal wave surface of the extraordinary ray being outside the spherical surface of the ordinary ray; Fig. 557 that of a *positive* crystal like quartz ($\omega < \epsilon$) with the ellipsoidal surface within that of the sphere. Fig. 558 is an attempt to show the relations of the two wave-fronts of a negative crystal in perspective for a single octant. The constant value of the velocity of the ordinary ray $\left(\frac{1}{\omega}\right)$, whatever its direction in the plane of Figs. 556 and 557, is expressed by the radius of the circle (= *OC*). On the other hand, the velocity of the extraordinary ray in the horizontal direction is given by *OA* $\left(\frac{1}{\epsilon}\right)$, while in any oblique direction, as *Osr*, Fig. 556 (*Ors*, Fig. 557), it is

556



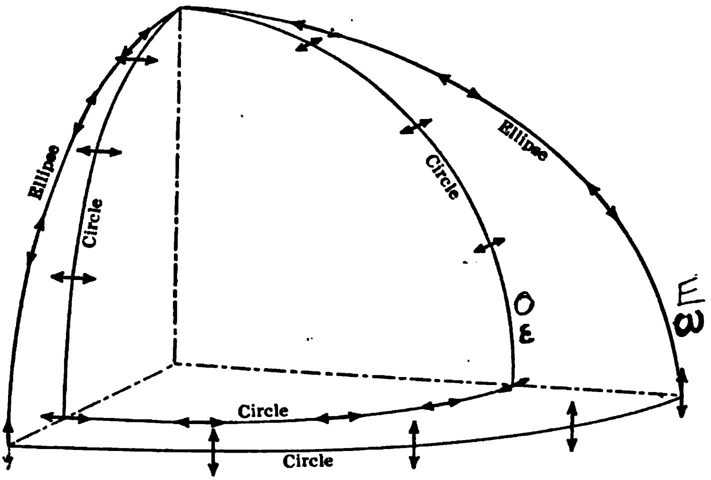
Negative crystal, $\epsilon < \omega$.

557



Positive crystal, $\omega < \epsilon$.

558

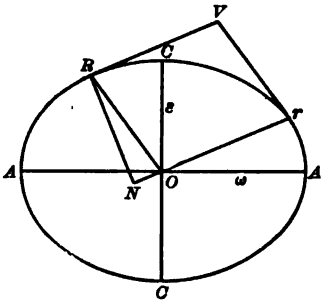


expressed by the length of this line, becoming more and more nearly equal to $OC\left(\frac{1}{\omega}\right)$ as its direction approaches that of the vertical axis.

382. Uniaxial Indicatrix. — The optical structure of a uniaxial crystal can be represented by an ellipsoid of revolution, called the *Indicatrix*,* from which can be obtained the directions of vibration and indices of refraction of the ordinary and extraordinary rays derived from any single incident ray. Fig. 559 represents a principal section of such an ellipsoid for an optically negative crystal, the line C–C being its axis of revolution. The axes of this ellipsoid are made inversely proportional to the indices of refraction of the two rays, ω and ϵ, as follows:

$$OC : OA = \frac{1}{\omega} : \frac{1}{\epsilon} \text{ or } \epsilon : \omega.$$

559



In this figure let Or be a direction of transmission of light. Let Vr and VR be tangents to the elliptical surface at the points r and R and OR be a radius vector parallel to the tangent Vr. Or and OR form then what are known as *conjugate radii.* From the geometrical properties of an ellipse it follows that the area of any parallelogram with conjugate radii forming two sides, such as $ORVr$ in Fig. 559, is constant and equal to the area of a parallelogram having OC and OA as two sides. Let RN be perpendicular to the extended line Or. Then the area of $ORVr$ will be equal to $RN \cdot Or$. It follows since $RN \cdot Or = OA \cdot OC$ = a constant, k, that

$$Or = \frac{OA \cdot OC}{RN} = \frac{k}{RN}\text{; also } OA = \frac{k}{OC}$$

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* The Optical Indicatrix and the Transmission of Light in Crystals, by L. Fletcher, London, 1892.

From the last expression we see that *OA* and *OC* are inversely proportional to each other, or, in other words, as *OC* represents the minimum index, *OA* will represent the corresponding velocity of light which will be the maximum for any transmission direction in the crystal. In the same way *Or* and *RN* are inversely proportional to each other, the distance *Or* representing the velocity of the extraordinary ray traveling along that direction while *RN* will represent its refractive index. The line *RN* will also give the direction of vibration of the extraordinary ray.

For the radius vector *Or* there will be another possible direction perpendicular to it and also normal to the ellipsoidal surface. This will be a line from *O* perpendicular to the principal section represented in Fig. 559. This line will lie in the horizontal circular section of the indicatrix ellipsoid with its length equal to *OA* which in turn is proportional to the index of the ordinary ray, ω. So for a given direction of transmission of light, such as *Or*, the two lines that are perpendicular to it and at the same time normal to the surface of the indicatrix yield both the indices of refraction of the two rays and the directions of their vibrations.

If, however, the light is passing parallel to the principal axis of the indicatrix, *i.e.*, *C–C*, Fig. 559, there will be an infinite number of lines which are perpendicular to this direction and at the same time normal to the surface of the indicatrix. These will lie in the horizontal circular section of the ellipsoid and consequently will be of a uniform length. From this it is evident that such a transmitted ray may vibrate in any transverse direction and will possess a single index of refraction and velocity. Along this direction, known as the optic axis, there will consequently be no double refraction of the light.

383. Examples of Positive and Negative Crystals. — The following lists give prominent positive and negative uniaxial crystals, with the values of the refractive indices, ω and ϵ, for each, corresponding to yellow sodium light.* The difference between these, $\omega - \epsilon$ or $\epsilon - \omega$, is also given; this measures the birefringence or *strength* of the double refraction.

It may be remarked that in some species both + and − varieties have been observed. Certain crystals of apophyllite are positive for one end of the spectrum and negative for the other, and consequently for some color between the two extremes it has no double refraction. The same is true for some other species (*e.g.*, chabazite) of weak double refraction.

NEGATIVE CRYSTALS

	ω	ϵ	$\omega - \epsilon$
Proustite	2·979	2·711	0·268
Calcite	1·658	1·486	0·172
Tourmaline	1·638	1·620	0·018
Corundum	1·768	1·760	0·008
Beryl	1·584	1·578	0·006
Vesuvianite	1·720	1·715	0·005
Nephelite	1·542	1·538	0·004
Apatite	1·634	1·631	0·003

POSITIVE CRYSTALS

	ω	ϵ	$\epsilon - \omega$
Rutile	2·616	2·903	0·287
Cassiterite	1·997	2·093	0·096
Zircon	1·923	1·968	0·045
Brucite	1·559	1·580	0·021
Phenacite	1·654	1·670	0·016
Quartz	1·544	1·553	0·009
Apophyllite	1·535	1·533	0·002
Leucite	1·508	1·509	0·001

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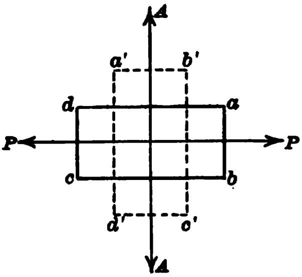
* From tables by E. S. Larsen.

Examination of Uniaxial Crystals in Polarized Light

384. Section Normal to the Axis in Parallel Polarized Light. — Suppose a section of a uniaxial crystal to be cut perpendicular to the vertical crystallographic axis. It has already been shown that light passing through the crystal in this direction suffers no double refraction; consequently, such a section examined in *parallel* polarized light behaves as a section of an isotropic substance. If the nicols are crossed it appears *dark,* or *extinguished,* and remains so when revolved.

385. Section Parallel to the Axis. — A section cut parallel to the vertical axis, as already explained, has two directions of light-vibration, one parallel to this axis, that of the extraordinary ray, and the other at right angles to it, that of the ordinary ray. A ray of light falling upon such a section with perpendicular incidence is divided into the two rays, ordinary and extraordinary, which travel on in the same path through the crystal, but one of them retarded relatively to the other. When such a section is examined in polarized light with crossed nicols it will appear dark, or be extinguished, when its vibration directions lie parallel to the vibration directions of the nicols. Assume that the section *abcd,* Fig. 560, lies with the direction of its vertical crystallographic axis parallel to *P–P,* which represents the vibration direction of the polarizer. The light entering the section under these conditions will be vibrating parallel to the vertical axis of the crystal and will therefore pass into the mineral wholly as the extraordinary ray, there being no vibration possible in the direction of the ordinary ray. The light will, therefore, leave the section with the same direction of vibration as when it entered and will be entirely lost by reflection in the analyzer. If the section is turned at an angle of 90°, as *a′b′c′d′,* Fig. 560, similar conditions prevail, although in this case the light will vibrate in the section as the ordinary ray. Therefore in such a section there will be four positions during its complete revolution on the stage of the polariscope or microscope when it will be extinguished.

560



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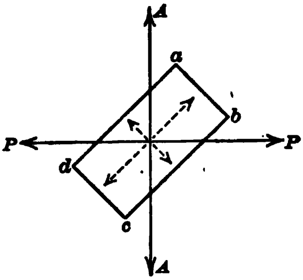

If the section stand obliquely, as *abcd* in Fig. 561, it will appear light to the eye (and usually colored), for the vibrations parallel to *P–P* that have passed through the polarizer have upon resolution a component in the direction of each of the vibration-planes of the section. Again, each of these components can be resolved along the direction of the vibration-plane of the upper nicol, *A–A.* Therefore, two rays will emerge from the analyzer, both having the same vibration-plane, but one more or less retarded with reference to the other, the amount of retardation increasing with the birefringence and the thickness of the section. In general, therefore, these rays will interfere, and if the thickness of the section is sufficient (and not too great) it will appear colored in white light and, supposing the thickness uniform, of the same color throughout.

386. Parallel Extinction. — When the vibration directions of a section coincide with those of the polarizer and analyzer, assuming them to be crossed, the section appears dark and it is said to be in the position of extinction. If a section extinguishes when its crystallographic axis or axial plane is parallel to one of the planes of vibration of the nicols it is said to show *parallel extinction.* If, on the other hand, no such parallelism exists between the crystallographic directions and the directions of vibration in the mineral the section is said to show *inclined extinction.*

In the case of uniaxial minerals, since the vibration directions always lie in some crystallographic axial plane, all sections of such minerals will show parallel extinction.

387. Determination of the Relative Character of the Extinction Directions of a Given Uniaxial Mineral. — The relative characters of the extinction directions of a section of a uniaxial mineral are to be determined by the use of the quartz wedge or the sensitive tint as described in Art. **348**. If the orientation of the section is known so that it can be told which of the directions of vibration belongs to the ordinary and which to the extraordinary ray the positive or negative character of the mineral can be determined. For instance, if the ordinary ray is proved to be the faster of the two (*i.e.*, the X direction) it follows that its index is the smaller, *i.e.*, $\omega < \epsilon$, and the mineral is positive.

388. Interference Colors of Uniaxial Minerals. Birefringence. — The interference color of any section of a uniaxial mineral depends upon the following: first upon the thickness of the section, second upon the strength of the double refraction of the mineral, *i.e.*, its birefringence, this being measured by the difference between the indices of refraction of the two rays in the section, and third upon the crystallographic orientation of the section. A section cut parallel to the basal plane shows no double refraction and therefore cannot exhibit any interference color. The strength of the birefringence, the other conditions remaining uniform, increases as the inclination of the section to the basal plane increases. The highest birefringence of a given mineral is therefore shown by its prismatic sections.

The following table * gives the thickness (in millimeters) of sections of a few uniaxial crystals which yield *red* of the first order:

	Birefringence $(\omega - \epsilon)$ or $(\epsilon - \omega)$	Thickness in Millimeters
Rutile	0·287	0·0019
Calcite	0·172	0·0032
Zircon	0·062	0·0089
Tourmaline	0·023	0·0240
Quartz	0·009	0·0612
Nephelite	0·004	0·1377
Leucite	0·001	0·5510

Again, as another example, it may be noted that with zircon ($\epsilon - \omega = 0·062$), a thickness of about 0·009 mm. gives red of the first order; of 0·017 red of the second order; of 0·026 red of the third order.

The methods ordinarily used to determine the birefringence of a section (not $\perp$ c axis) of a uniaxial crystal, as also to fix the relative value of its two vibration-directions, have already been discussed, see Arts. **347** and **348**.

389. Effects of Convergent Polarized Light upon Sections of Uniaxial Minerals. Uniaxial Interference Figures. — When certain sections of uniaxial minerals are observed in convergent polarized light they show what are known as *interference figures*. A symmetrical interference figure is obtained in uniaxial minerals by allowing converging polarized light to pass through a basal section of the crystal. Parallel polarized light entering such a section would suffer no double refraction and consequently give no interference. To convert the parallel polarized light that comes from the polarizer into convergent light a lens is placed between the polarizer and the section. Under these conditions a sharply converging cone of light rays enters the section. Another lens is placed above the section to change these oblique rays back again into a parallel postion. Such an instrument is known as a *conoscope* and may be obtained by placing a pair of lenses between the polarizer and analyzer of a polariscope, or, in case the polarizing microscope is used, the small converging lens that lies above the polarizer is swung into position by a lever and at the same time a small lens known as the Bertrand lens is introduced into the microscope tube.

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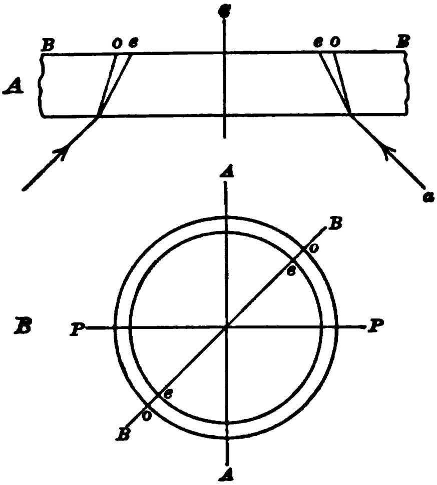
* See further, Rosenbusch (Mikr. Phys. Min., 1904, p. 292), from whom these are taken.

562



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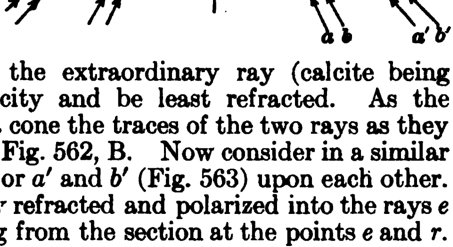


Under such conditions the light entering the section is composed of a converging system of rays polarized and vibrating in the plane *P–P*, Fig. 562. Let *B–B* (Fig. 562, *A*) be a vertical cross section of the mineral section along the line *B–B*, Fig. 562, B. Consider any ray, as *a*, entering the section. Since the ray enters the section obliquely it will be doubly refracted into the rays *o* and *e*. The mineral being taken as calcite the extraordinary ray (calcite being negative) will have the greater velocity and be least refracted. As the light enters the section in the form of a cone the traces of the two rays as they emerge from the section will be circles, Fig. 562, B. Now consider in a similar case the action of the two rays *a* and *b* or *a'* and *b'* (Fig. 563) upon each other. Ray *a* on entering the section is doubly refracted and polarized into the rays *e* and *o* which are considered as emerging from the section at the points *e* and *r*. Ray *b* also on entering the section is doubly refracted and polarized. Suppose the extraordinary ray derived from *b* emerges from the section at the same point as the ordinary ray derived from *a*, that is at *r*. Since it travels with a greater velocity the extraordinary ray emerging at this point will have advanced in its phase over that of the ordinary ray. In that case they would be in a condition to interfere with each other except that they are vibrating in planes perpendicular to each other and so cannot. The two rays travel on, vibrating in planes at right angles to each other and maintaining this difference in phase until they reach the upper nicol; there they are each resolved into rays vibrating in the plane *A–A*, Fig. 562, *B*, and are now in condition to interfere with each other. Let it be assumed that the conditions are right for the extraordinary ray to emerge from the section just one wave-length ahead of the ordinary ray. Their components in the upper nicol will have opposite phases and therefore compensate each other, see Art. **335.** If the section is viewed in a monochromatic light (for instance, sodium light) this interference will result in a black point. But as these rays are converging in the form of a cone they will make, when they strike the section, a circular trace upon its surface and their interference will result in a dark ring. Going out from the center of the section there will be a succession of these rings corresponding to the interference of waves 1, 2, 3, 4, 5, etc., wave-lengths apart. As the distance from the center of the section is increased, the paths of the refracted rays in the section are lengthened and the points of interference are brought closer together. This will cause the interference rings to lie nearer together as the distance from the center of the figure increases.

564

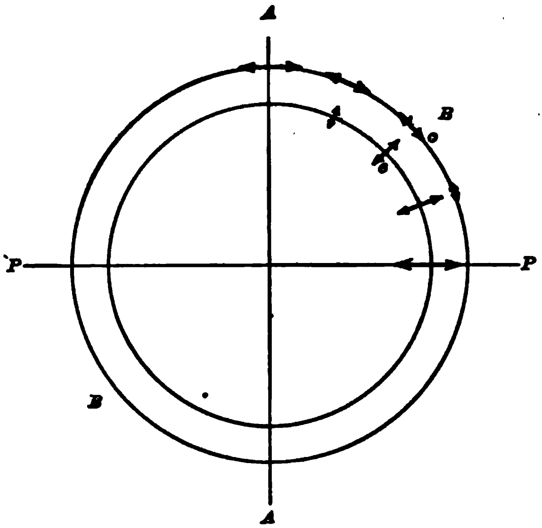
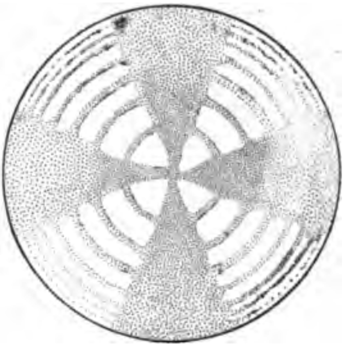


Fig. 564 is a top view of the section without taking into consideration the effects of the upper nicol. Let the two circles represent the traces of the emergence of the two rays *e* and *o* into which one incident conical ray is divided; *e*, being the least refracted (for calcite), will be the inner one. The plane of vibration of *e* is always parallel to some plane passing through the vertical axis of the crystal, therefore the trace of its plane of vibration upon the surface of the section will always be in a radial direction. The plane of vibration of *o* is at right angles to that of the extraordinary ray and parallel to the horizontal axes of the crystal, therefore the trace of its plane of vibration upon the surface of the section will always be in a tangential direction, see Fig. 564. Along the line *P–P*, Fig. 564, only light vibrating in a radial plane or that of the extraordinary ray can come through the section, since the light entering the section cannot be resolved into the vibrations of the ordinary ray. The intensity and direction of vibration of the light that emerges from the section along the line *P–P* is represented by the double arrow on that line. Along the line *A–A*, since the light entering the section is still vibrating in the plane *P–P*, all the light passing through the section must vibrate as the ordinary ray. It is evident, therefore, that along these two directions, *P–P* and *A–A* the plane of vibration of the light is not changed by passage through the section and consequently such light will be completely absorbed in the upper nicol. In this way dark brushes will be formed along the lines *P–P* and *A–A*. A dark spot will also be formed in the center of the field because any light entering the section at this point must enter in the direction of the optic axis and therefore will not be doubly refracted and consequently will also be absorbed in the analyzer.

Now consider point *B*, Fig. 564, which lies 45° away from *P* and *A*. Here the directions of vibration of *e* and *o* would be equally inclined to the planes of vibration of the polariscope, *A–A* and *P–P*. Light striking the section at *B* would be vibrating in the plane *P–P* but by resolution a component vibrating in the direction *B–B* would come through the section as the ray *e;* in the same manner a component vibrating in a direction at right angles to *B–B* would emerge as *o*. The intensities and directions of vibration of these two rays at this point are represented by the double arrows. When these rays meet the analyzer above they would again each be resolved and their components which vibrate in the plane *A–A* would emerge from the analyzer. In this way it is seen that, except at the special points where complete interference takes place, light will result in the interference figure at all points away from the center of the figure and from the lines *P–P* and *A–A*. From the consideration of Fig. 564 it is evident that the greatest amount of light will come through the section at the 45° points, such as *B*. When viewed in monochromatic light, therefore, the interference figure consists of a series of concentric dark and light rings crossed by a vertical and a horizontal dark brush intersecting in the center of the field of the microscope, like Fig. 565.

565



Uniaxial Interference Figure

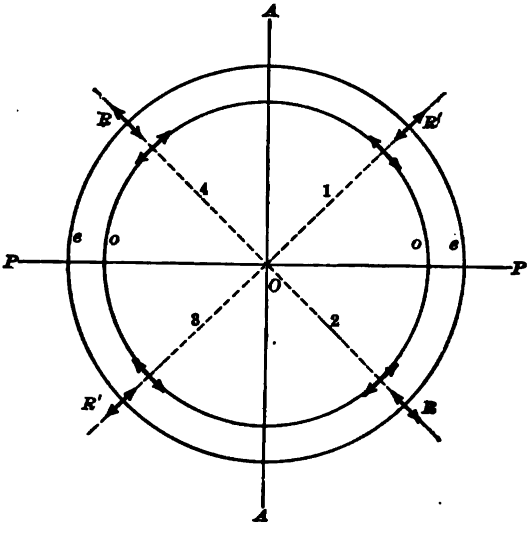
If a basal section of a uniaxial mineral while in the conoscope is viewed in daylight colored rings will take the place of the light and dark rings observed in the monochromatic light. The change will be like that shown by the quartz wedge in the similar case described in Art. **343**. Where the first few dark rings near the center of the figure were formed by the interference of rays having the wave-length of sodium, light colored rings will result in the daylight illumination. These rings will be composed of all the components of white light with the yellow of sodium subtracted. The other colors are obtaind in a similar manner by the elimination though interference of some particular wave-length of light. While the interference figure when illuminated in the monochromatic light showed a large number of distinct black rings in daylight. the corresponding colored rings are limited in number and their colors, gradually becoming fainter as the distance from the center of the figure increases, finally merge into the white of the higher order. This is due to the overlapping of the interference rings of the various colors in the same manner as observed in the quartz wedge, see Art. **343**. The interference figure viewed in daylight will of course retain the black cross and center since these are due to the cutting out of all the light by the analyzer and are not the result of interference.

The distance of each successive ring from the center of the interference figure obviously depends upon the birefringence, or the difference between the refractive indices, for the ordinary and extraordinary ray, and also upon the thickness of the plate. The stronger the double refraction and the thicker the plate, the smaller the angle of the light-cone which will give a certain amount of retardation, or, in other words, the nearer the circles will be to the center. Further, for the same section the circles will be nearer for blue light than for red, because of their shorter wave-length. When the plate is either quite thin or quite thick only the black brushes will be distinctly seen.

390. Determination of the Positive or Negative Character of the Birefringence of a Uniaxial Mineral from Its Interference Figure.

Use of the Mica Plate. — For the identification of a uniaxial mineral it is naturally important to determine whether the character of its birefringence is positive or negative. This can usually be best accomplished by tests made upon its interference figure. One of the common ways of making this test is by the use of a sheet of muscovite mica, cleaved so thin that, of the two rays of light passing through it, one has gained one quarter of a wave-length in phase over the other. The mica is usually mounted between long and narrow glass plates and is known as the one quarter wave-length mica plate. It is commonly marked *1/4M* with an arrow indicating the *Z* optical direction. In testing an interference figure by means of the mica plate the latter is inserted somewhere between the polarizer and analyzer (in the microscope commonly through the slot just above the objective) and is so orientated that the *Z* direction makes an angle of 45° with the planes of vibration of the nicols.

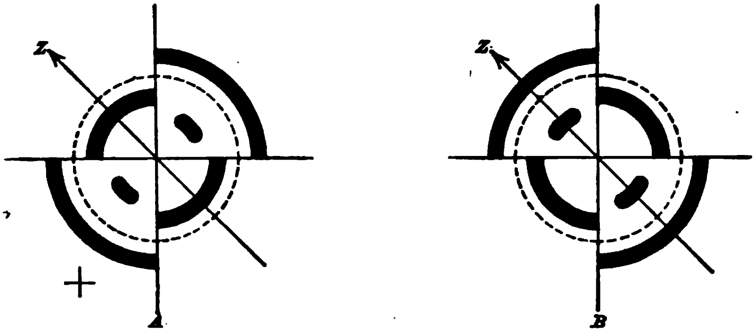
566



In Fig. 566 let *P–P* represent the plane of vibration of the polarizer and *A–A* the plane of vibration of the analyzer of a conoscope. Let *O* be the point of emergence of the optic axis of a positive uniaxial mineral. Suppose a single conical ray of light enters the section. It is broken up in the mineral into two rays, *o* and *e*, which emerge from the section along the arcs of the circles shown in Fig. 566. The trace of the ordinary ray, *o*, will be within that of the extraordinary ray, *e*, because in a positive mineral the *o* ray travels the faster and is less refracted. The directions of vibration of these two rays at the 45° points *R* and *R'* are represented by the double-headed arrows. When these rays reach the analyzer they will be resolved into components vibrating parallel to *A–A*. There are an infinite number of such rays entering and passing through the mineral section with varying angles of inclination and therefore varying lengths of path. At some certain distance out from the center *O* two rays will emerge on the same circle with a difference of phase of one whole wave-length and when resolved in the upper nicol into rays vibrating in the same plane will interfere with each other and produce the first dark ring of the interference figure as it is viewed in monochromatic light.

If the mica plate is introduced above the section a change in the interference figure is noted. The optical character of the mica cannot be fully explained at this point. It is sufficient for present purposes to know that it is a doubly refracting mineral which breaks light up into two rays which are polarized in planes at right angles to each other and which, traveling with different velocities through the mica, will emerge from it with different phases. As stated above, the mica plate is cleaved to the requisite thickness so that the two rays emerge from it with a difference of phase of one quarter of a wave-length. Consider what takes place when such a plate is introduced above the section represented in Fig. 566 in such a position that its vibration direction *Z* is parallel to the direction *R–O–R* of the figure. Consider what takes place at the points *R*. There the vibration direction of the *e* ray coincides with the vibration direction *Z* of the mica plate. These vibration directions in each case are those of the rays traveling with the smaller velocity. On the other hand, at the same point the vibration direction of the *o* ray in the mineral coincides with the vibration direction *X* in the plate, both of these being of the rays with the greater velocity. So at this point the effect of the mica plate is to increase the difference of phase between *o* and *e* and to produce the same result as if the mineral section had been thickened. Consequently the interference rings along the line *R–O–R* are increased in number and drawn toward the center of the figure. At the points *R′* the opposite is true. The vibration direction of *e* coincides now with that of *X* in the mica plate; the direction of least velocity in the mineral with that of the greatest in the mica. Also the vibration direction of *o* coincides with that of *Z*; that of the greater velocity in the mineral with the less velocity in the mica. So at this point the mica will decrease the difference in phase between *o* and *e* and produce the effect of thinning the section and so spreading the interference rings farther apart along the line *R′–O–R′*. In quadrants 2 and 4, therefore, the rings will be drawn nearer the center, while in quadrants 1 and 3 they will be spread farther apart. Another effect caused by the introduction of the mica plate is even more pronounced. In quadrants 1 and 3, in the case illustrated in Fig. 566, black dots will appear near the center of the figure. In the interference figure, before the introduction of the mica plate, there were points in quadrants 1 and 3 at short distances from the center, *O*, where the two rays, *o* and *e*, emerged from the section with a difference of phase of one quarter wave-length. Under these conditions no interference could take place and these spots were light. The effect of the mica plate in these two quadrants is to everywhere reduce the birefringence due to the mineral by one quarter of a wave-length. Therefore at these two points the difference of phase caused by the birefringence of the mineral is annulled by the mica plate and consequently at these points interference will result and black dots appear. The mica plate produces still other effects. The brushes which were dark in the interference figure become light. Light coming from the crystal section along the lines of the brushes is vibrating only in the vibration direction of the polarizer and ordinarily is wholly cut out by the analyzer above. But with the mica plate intervening this light is broken up in the mica into two rays which vibrate in the vibration planes of the mica and as these are inclined to the plane of the analyzer a portion of the light will come through to the eye. As the light coming from the section along the lines of the brushes had only a single velocity (was entirely either the ordinary or extraordinary ray) there are only two rays emerging from the mica plate along these directions and their difference of phase is one quarter of a wave-length. Under these conditions there can be no interference and white brushes result. In the same way the dark center of the interference figure becomes light.

567



Determination of Optical Character with Mica Plate

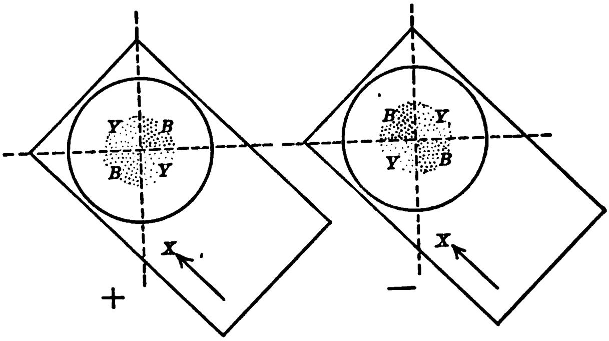
Fig. 567, *A*, is a diagrammatic representation of the interference figure of a positive mineral as affected by the insertion of the mica plate, the direction of the arrow indicating the direction Z of the mica, *i.e.*, the direction of vibration of the ray having the smaller velocity. In the case of a negative mineral the conditions as described above will be completely reversed. Fig. 567, *B*, represents the appearance of an interference figure of a negative mineral when the mica plate is used.

Therefore, to determine the optical character of a uniaxial mineral from its interference figure insert a mica plate above the section with its Z direction making 45° with the vibration planes of the nicols. Then, if this direction Z is at right angles to a line joining the two black dots that appear near the center of the figure (*i.e.*, the two lines form a plus sign), the mineral is positive; if, on the other hand, these two directions coincide (form together a minus sign) the mineral is negative.

Use of the Sensitive Tint. — The sensitive tint, see Art. **344**, is used to determine the positive or negative character of a uniaxial mineral from its interference figure when the mineral section is so thin, or the mineral possesses such a low birefringence, as to show in the figure only a black cross without any rings. Under such conditions the mica plate would not give a decisive test. The sensitive tint is usually so mounted that its longer direction coincides with the direction of the vibration of the faster ray, *i.e.*, the direction X. The sensitive tint is introduced somewhere between the polarizer and analyzer in such a position that its vibration directions are at 45° with the planes of vibration of the nicols. Let it be assumed that we have the interference figure from a positive mineral, such as is represented in Fig. 566. If the sensitive tint is introduced in such a position that its X direction is parallel to the line R–O–R the X direction of the sensitive tint will be parallel to the direction of vibration of the *e* ray in the mineral. Since the mineral is positive the *e* ray will have the smaller velocity and therefore in quadrants 2 and 4 the optical orientation of the mineral and the sensitive tint will be opposed to each other. The sensitive tint alone would produce an interference color of red of the first order. But if the effect of the birefringence of the mineral is such as to subtract from the birefringence of the sensitive tint the color will change to yellow. Consequently in these quadrants yellow spots will appear near the center of the field at the points where the effect of the mineral has been sufficient to lower the interference color to that extent. In the other quadrants, 1 and 3, the faster and slower rays of the mineral and sensitive tint coincide in their directions and the effect of the two substances is an additive one. Consequently in these two quadrants the color will rise to blue.

In making the above test with the sensitive tint it is convenient to follow the rule that if the direction *X* of the sensitive tint crosses a line uniting the two blue dots (makes a plus sign) the mineral is positive; if, on the other hand, these two directions coincide (make together a minus sign) the mineral is negative. These conditions are illustrated in Fig. 568.

568



Determination of Optical Character with Sensitive Tint

391. Interference Figures from Inclined Sections of Uniaxial Minerals. — It frequently happens that a mineral section under observation for an interference figure is not cut exactly parallel to the basal plane of the crystal.

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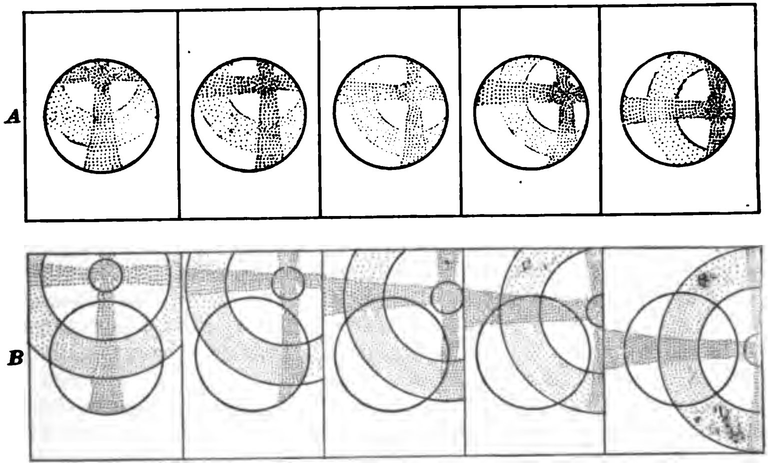
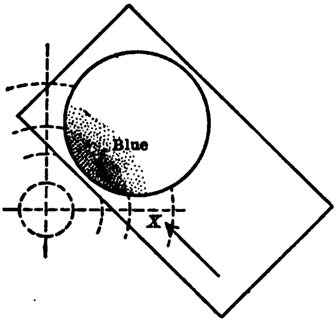


Eccentric Uniaxial Interference Figures

An interference figure obtained from such an inclined section will of course be eccentric to the microscope field. If the section is inclined only a little to the basal plane, the center of the figure (*i.e.*, the point of emergence of the optic axis) will still be within the field of vision and will move in a circle about the center of the field when the section is revolved upon the microscope stage. Fig. 569, A, shows the successive positions of such an interference figure during revolution. If the section is more sharply inclined the center of the interference figure may be quite outside the field. As the section is turned on the stage the four arms of the interference cross will traverse the field in succession. They will move across the field as straight bars and, provided the section has been cut not too highly inclined to the optic axis, will move across the field parallel to the cross-hairs of the microscope. This fact is of importance in order to distinguish such a uniaxial interference figure from certain biaxial figures. The latter will often show similar bars which, however, will always curve as they cross the field of the microscope. If the first of these bars in the uniaxial figure moves from left to right across the field, the second will move from the top to the bottom, the third from right to left and the last from the bottom to the top, etc. Fig. 569, B, shows the different position of such a figure during one quarter of a revolution.

The positive or negative character of the mineral can usually be determined from an eccentric figure if care is taken to make certain which quadrant is visible when the test is made. For instance, in Fig. 570 is shown how the test is made with the sensitive tint upon the eccentric interference figure of a positive mineral.

570



Sensitive Tint with Eccentric Interference Figure

In examining unorientated sections of a mineral, such as the random section found in a rock section or the small fragments of a mineral placed upon a glass slide, it is advisable always to hunt for that section that gives the lowest interference color. The amount of birefringence shown in various sections of a uniaxial mineral decreases as the section approaches the orientation of the basal plane. Consequently that section showing the lowest interference color will yield the most nearly symmetrical interference figure.

392. Interference Figure from a Prismatic Section of a Uniaxial Mineral. — When a prismatic section of a uniaxial mineral is examined for an interference figure an indefinite result is obtained. The figure is analogous to one obtained in the case of biaxial crystals. The reasons for this resemblance will be pointed out in a later article. The two types of figures cannot be in this case easily differentiated. Two dark and usually indefinite hyperbolas approach each other as the section is turned on the microscope stage, form an indistinct cross, and rapidly separate. These bars differ from those obtained in a biaxial interference figure in that they rapidly fade out as they move away from the crossed position. This type of interference figure can be obtained easily from the quartz wedge.

393. Absorption Phenomena of Uniaxial Crystals. Dichroism. — When light enters colored minerals as rays of white light, *i.e.*, containing vibrations of all wave-lengths from that of violet light at one end of the spectrum to that of red light at the other, certain wave-lengths will be absorbed during the passage of the light through the mineral, so that the light, as it emerges, has a definite color. It happens in certain deeply colored minerals that the amount and character of this absorption depends upon the direction of the light vibration. For instance in the case of uniaxial minerals, the ordinary and extraordinary rays may emerge from the section with distinctly different colors. Take, for instance, a prismatic section of a brown colored tourmaline and observe it in plane polarized light without the use of the upper nicol. As the section is revolved upon the stage of the polariscope the color may change from a dark brown to a light yellow-brown. The greatest difference in the color occurs at positions 90° apart and when the crystallographic directions of the section, *i.e.*, the vertical crystallographic axis and the trace of the plane of the horizontal axes, are either parallel or perpendicular to the vibration plane of the polarizer. In other words, these extremes of color occur when the directions of the vibration of the ordinary and extraordinary rays in the section are parallel or perpendicular to the vibration plane of the light entering the section. In Fig. 571, *A*, let *P–P* represent the vibration direction of the light entering the section. The mineral section is so placed that the direction of the vertical crystal axis is perpendicular to *P–P*. The light on entering the section will therefore vibrate in the plane of the horizontal axes or as the ordinary ray, *o*. In this position the tourmaline section is dark colored and consequently it is seen that light vibrating in the mineral as the ordinary ray is largely absorbed. Now turn the section through a 90° angle to the position shown in Fig. 571, *B*. In this position the light must vibrate in the section wholly as the extraordinary ray, *e*, and the color is a light yellow-brown. Therefore the extraordinary ray is only slightly absorbed. This difference in the absorption or the color of the two rays is known as *dichroism*. Either the ordinary or the extraordinary ray may be the most absorbed and the two cases are expressed as either $o > e$ ($\omega > \epsilon$) or $e > o$ ($\epsilon > \omega$). In uniaxial minerals dichroism is to be best observed in prismatic sections where it attains its full intensity. Basal sections show no dichroism, since light passing through the section parallel to the optic axis must all vibrate in the horizontal axial plane and belong wholly to the ordinary ray.

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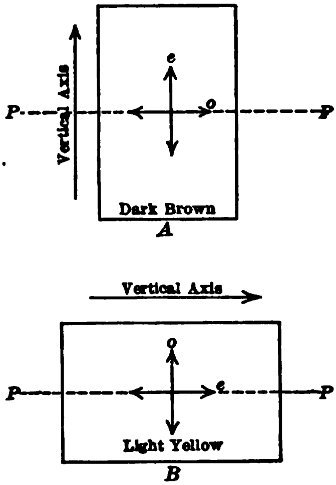

An instrument called a *dichroscope*, contrived by Haidinger, is sometimes used for examining this property of crystals. An oblong rhombohedron of Iceland spar is placed in a metallic cylindrical case, having a convex lens at one end, and a square hole at the other. On looking through it, the square hole appears double; one image belongs to the ordinary and the other to the extraordinary ray. When a pleochroic crystal is examined with it by transmitted light, on revolving it the two squares, at intervals of 90° in the revolution, have different colors, corresponding to the vibration-planes of the ordinary and extraordinary ray in calcite. Since the two images are situated side by side, a very slight difference of color is perceptible. A similar device is sometimes used as an ocular in the microscope.

394. Circular Polarization. — The subject of elliptically polarized light and circular polarization has already been briefly alluded to in Art. 360. This phenomenon is most distinctly observed among minerals in the case of crystals belonging to the rhombohedral-trapezohedral class, that is, quartz and cinnabar.

It has been explained that a section of an ordinary uniaxial crystal cut normal to the vertical (optic) axis appears dark in parallel polarized light for every position between crossed nicols. If, however, a similar section of quartz, say 1 mm. in thickness, be examined under these conditions, it appears dark in monochromatic light only, and that not until the analyzer has been rotated so that its vibration-plane makes for sodium light an angle of 24° with that of the polarizer. In other words, this quartz section has rotated the plane of vibration some 24°, and here either to the right or to the left, looking in the direction of the light. The *amount* of this rotation increases with the thickness of the section, and, as the wave-length of the light diminishes (for red this angle of rotation for a section of 1 mm. is about 19°, for blue 32°). The direction of the rotation is to the right or left, as defined above — according as the crystal is crystallographically right-handed or left-handed (p. 113).

If the same section of quartz (cut perpendicular to the axis) be viewed between crossed nicols in converging polarized light, it is found that the interference-figure differs from that of an ordinary uniaxial crystal. The central portion of the black cross has disappeared, and instead the space within the inner ring is brilliantly colored.* Furthermore, when the analyzing nicol is revolved, this color changes from blue to yellow to red, and it is found that in some cases this change is produced by revolving the nicol to the *right*, and in other cases to the *left;* the first is true with right-handed crystals, and the second with left-handed. If sections of a right-handed and left-handed crystal are placed together in the polariscope, the center of the interference-figure is occupied with a four-rayed spiral curve, called, from the discoverer, *Airy's spiral*. Twins of quartz crystals are not uncommon, consisting of the combination of right- and left-handed individuals (according to the Brazil law) which show these spirals of Airy. With cinnabar similar phenomena are observed. Twins of this species also not infrequently show Airy's spirals in the polariscope.

395. Summary of the Optical Characters of Uniaxial Crystals. — All sections of uniaxial crystals show double refraction except those that are cut parallel to the basal plane. All doubly refracting sections show parallel extinction. When viewed in convergent polarized light with crossed nicols all sections show a characteristic uniaxial interference figure except those that lie in the prism zone of the crystal or that are only slightly inclined to that zone. All doubly refracting sections have two refractive indices corresponding to the two extinction directions: one of these is *always* ω and the other has a value (ϵ') ranging from ω to ϵ, dependent on the inclination of the section to the optic axis. Dark colored minerals may show dichroism. Tetragonal and hexagonal substances cannot be distinguished from each other by optical tests. They may be at times told apart by characteristic cross sections of their crystals.

C. BIAXIAL CRYSTALS

General Optical Relations

The crystals of the remaining systems, *i.e.*, the orthorhombic, monoclinic, and triclinic belong optically to what is known as the Biaxial Group.

396. The Behavior of Light in Biaxial Crystals. — In biaxial crystals there are three especially important directions at right angles to each other which are designated as X, Y, and Z (also $\mathfrak{a}$, $\mathfrak{b}$, and $\mathfrak{c}$). These three directions are sometimes spoken of as *axes of elasticity* in reference to certain assumed differences in the ether along them. The nature of these three directions is as follows. Light which results from vibrations parallel to X (axis of greatest elasticity) is propagated with the maximum velocity; that from vibrations parallel to Z (axis of least elasticity) with minimum velocity; and that from vibrations parallel to Y with an intermediate velocity. It is to be emphasized that these directions, X, Y, and Z refer to directions of vibration and not to directions of propagation. Corresponding to the maximum, intermediate, and minimum light velocities are three principle indices of refraction, designated respectively as α, β, and γ. Of these α, belonging to light with the maximum velocity, will have the least value and γ belonging to light with the minimum velocity, will have the greatest value. The value of β will be intermediate between the other two, sometimes being nearer to α and at other times being nearer to γ; it is not the arithmetical mean between them. The various methods of determining the values of these three principal indices of refraction will be considered in a later article.

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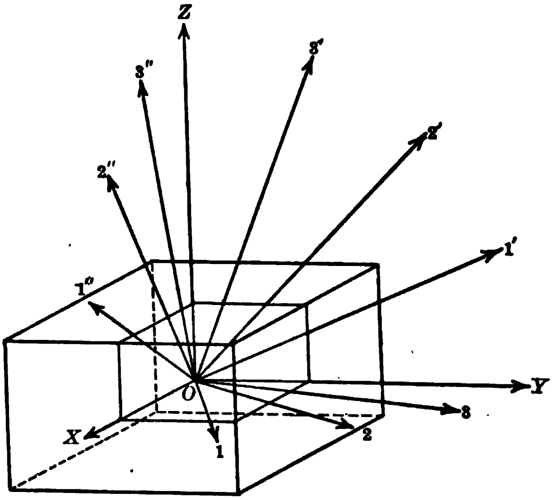
* Very thin sections of quartz, however, show (*e.g.*, with the microscope) the dark cross of an ordinary uniaxial crystal.

572



In studying the propagation of light within a biaxial crystal let it be assumed that Fig. 572 represents a rectangular parallelopiped in which the front to back axis is the direction X, the left to right axis is Y, and the vertical axis is Z. In connection with the figure and those which follow it is helpful to make use of a model (a pasteboard box would answer) orientated so that its longer edge runs from front to back, its mean edge from left to right and its shortest edge vertical, corresponding to the X, Y, and Z directions of the figure. In the development of the figures that follow it has been assumed that the three principle indices of refraction are $\alpha = 1.5$, $\beta = 1.6$, $\gamma = 2.5$, a difference between α and γ far exceeding anything observed in actual crystals. In general, this difference does not exceed 0.1; hence it is necessary to greatly exaggerate the actual values in order that the phenomena may be distinctly shown by diagrams drawn on a small scale.

In the discussion that follows it will be assumed that light originates at the center of a crystal, O, Fig. 572, and the endeavor will be made to determine the character of the rays which radiate from O in all directions. The simplest directions, and the ones which in reality are the most important, are those that lie in the axial planes of the figure, XOY, YOZ, and XOZ. These will be considered first.

Consider the plane of the X and Y directions, Fig. 572. Light will radiate from O toward X and Y and in all intermediate directions with vibrations parallel to Z and hence traveling with a uniform and at the same time minimum velocity, $1/\gamma$. The distance such light will travel in a given moment of time may be plotted by drawing a circle about O with the radius, $1/\gamma$, Fig. 573. In the direction OX there must also travel a second polarized ray resulting from vibrations parallel to *OY*, hence traveling with mean velocity $1/\beta$. Likewise in the direction *OY* there will be a ray resulting from vibrations parallel to *OX*, hence traveling with the maximum velocity, $1/\alpha$. In all directions intermediate between *X* and *Y* the light velocities will be proportional to the radii of an ellipse having $1/\beta$ and $1/\alpha$ respectively as its semi-minor and semi-major diameters, Fig. 573. In the plane of the *X* and *Y* directions, therefore, in a given moment of time light will radiate from the center as ordinary and extraordinary rays, the wave fronts being represented by a circle within an ellipse.

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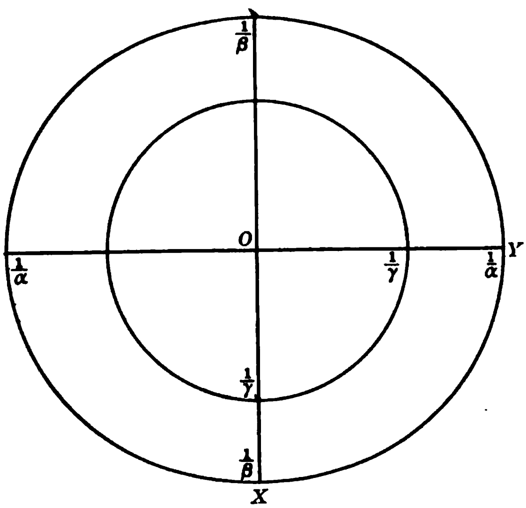

Consider next the plane of the *Y* and *Z* directions, Fig. 572. Light will radiate from *O* toward *Y* and *Z* and in all intermediate directions resulting from vibrations parallel to *OX*. It will therefore travel with uniform and the maximum velocity, $1/\alpha$. The distance traveled in a given moment of time may be plotted by drawing a circle about *O* with the radius $1/\alpha$, Fig. 574. Likewise there will travel in the direction *OY* a second ray resulting from vibrations parallel to *OZ*, hence moving with the minimum velocity, $1/\gamma$. Also in the direction *OZ* there will be a ray resulting from vibrations parallel to *OY* with the velocity $1/\beta$. In directions intermediate between *Y* and *Z* the light velocities will be proportional to the radii of an ellipse having $1/\gamma$ and $1/\beta$ respectively as its semi-minor and semi-major diameters, Fig. 574. In the plane of the *Y* and *Z* directions, therefore, in a given moment of time, light will radiate from the center as ordinary and extraordinary rays, the wave fronts being represented by an ellipse within a circle.

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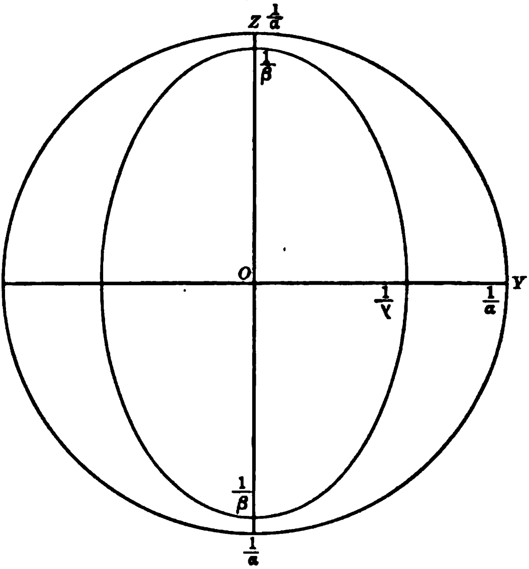

The last and most important plane to be considered is that of the X and Z directions, Fig. 572. Light will radiate from O toward X and Z and all intermediate directions with vibrations parallel to OY, hence traveling with a uniform and intermediate velocity, $1/\beta$. The distance traveled in a given moment of time is represented in Fig. 575 by the circle with the radius $1/\beta$. There will likewise travel in the direction OZ a ray resulting from vibrations parallel to OX, hence moving with the maximum velocity, $1/\alpha$. Also a ray will travel in the direction OX with vibrations parallel to OZ, hence having the minimum velocity, $1/\gamma$. In intermediate positions the light velocity will be proportional to the radii of an ellipse with $1/\alpha$ and $1/\gamma$ respectively as its semi-major and semi-minor diameters, Fig. 575. In the plane of the X and Z directions, therefore, in a given moment of time, light will radiate from the center as ordinary and extraordinary rays, the wave fronts represented by a circle intersecting an ellipse. It is to be noted that in this last plane there are four points where the two wave fronts coincide. In other words, light traveling along the radial lines connecting these points will be moving with uniform velocity and consequently along these directions there will be no double refraction. These directions are known as the optic axes of the crystal and since there are two of them the optical group is spoken of as biaxial. The character of these optic axes will be more fully developed in a later article.

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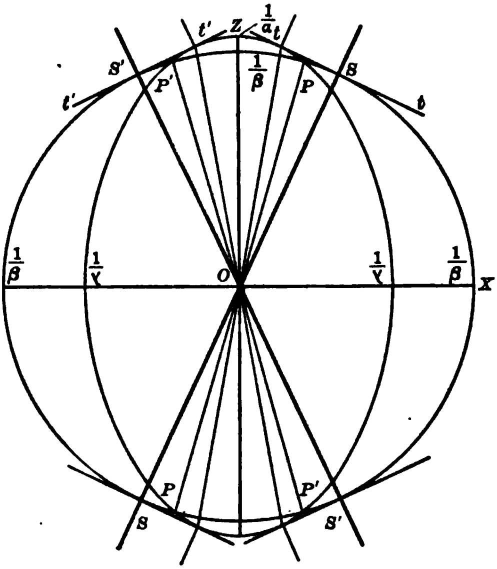

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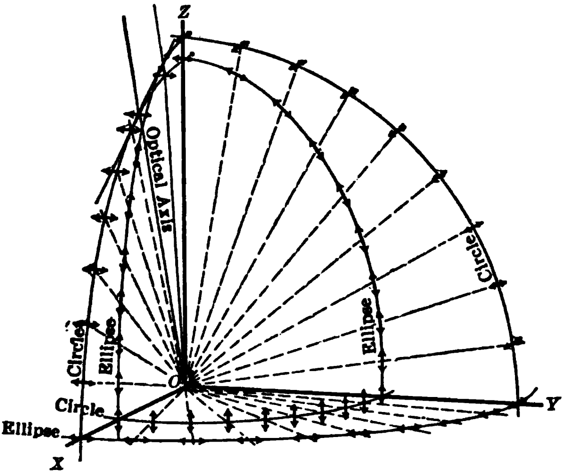
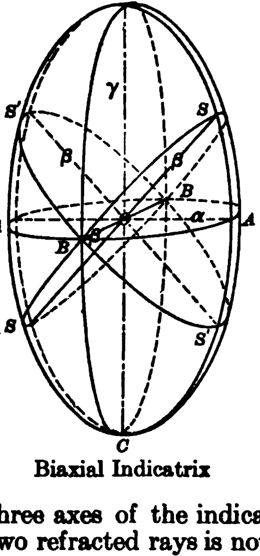


In the above paragraphs the wave fronts for light moving in the three principal optical planes of the crystal have been discussed. Fig. 576 represents the wave fronts in these three planes as they appear when bounding one octant. The complete wave surfaces for light propagated in all directions consist of warped figures which conform to the circular or elliptical wave fronts already described in the three principal planes and have intermediate positions elsewhere. The only satisfactory way to represent these complete surfaces is by means of a model.

397. Biaxial Indicatrix. — It is found further that the optical structure of a biaxial crystal can be represented by an ellipsoid, known as the *indicatrix,* having as its axes three lines which are at right angles to each other and proportional in length to the indices α, β, γ. This is analogous to the similar figure for uniaxial crystals described in Art. 382.

577



Biaxial Indicatrix

This ellipsoid, whose axes represent in magnitude the three principal refractive indices, α β, γ (where $\alpha < \beta < \gamma$), (see Fig. 577), not only exhibits the character of the optical symmetry, but from it may be derived the direction, velocity and plane of vibration of any light ray traversing the crystal.

In general it may be stated that the character of the two light rays which result from a single incident ray may be derived from a study of that elliptical section of the indicatrix which is normal to the incident ray. If this section happens to be one of the three principal sections of the indicatrix, *ABAB*, *ACAC*, or *BCBC*, Fig. 577, its major and minor diameters give the directions of vibration and their semi-lengths the indices of refraction of the two rays. If the incident ray has some direction different from the directions of the three axes of the indicatrix ellipsoid the derivation of the character of the two refracted rays is not as simple. Let Fig. 578 represent such an elliptical section normal to the inclined ray *L–L*. In this case the major and minor diameters *R–O–R* and *r–O–r* of the elliptical section lie in the vibration planes of the two rays but the directions of vibration of the latter will be somewhat inclined to the elliptical section. These directions of vibration may be obtained by erecting normals to the surface of the indicatrix at the points *R* and *r* where the major and minor diameters of the elliptical section meet that surface. These normals *RN* and *rn*, when extended to the line of the incident ray *L–L*, yield the directions of vibration and the refractive indices of the two refracted rays. Their directions of transmission (the lines *OS* and *OT*) will be perpendicular to these normals and since neither of the latter lie in the elliptical section both rays will be refracted and behave as extraordinary rays.

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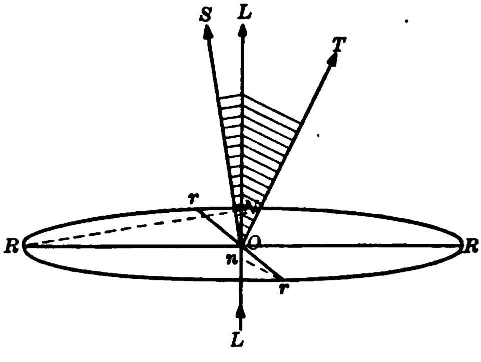

There are two special sections of the indicatrix that require notice. The line *B–O–B* (Fig. 577) is longer than the line *A–O–A* but shorter than the line *C–O–C*. Obviously, in some position intermediate between *A–O–A* and *C–O–C* there will be a diameter of the ellipse *ACAC* which will be equal in length to *B–O–B*. There are two such lines, as *S–O–S* and *S′–O–S′* in Fig. 577. The major and minor diameters of these sections of the indicatrix, *BSBS* and *BS′BS′*, are equal and the sections therefore become circles. Consequently light passing through a section of a crystal cut parallel to either of these circular sections of its indicatrix will have a uniform velocity and may vibrate in any transverse direction. In other words, there will be no double refraction along the lines normal to these two sections. These lines constitute what are known as the primary optic axes of the crystal; see further in Art. **398.**

The major and minor diameters of any section of the indicatrix yield the traces upon that section of the planes of vibrations of the two rays into which the ray normal to the section is refracted. In other words, the major and minor diameters of the elliptical section of the indicatrix give the directions of extinction of a crystal section having this optical orientation. Further, these extinction directions bisect the angles made by the traces upon the section of two planes, each of which includes the pole of the section and one of the two optic axes. This may be demonstrated by aid of Fig. 579 which represents a general elliptical section of an indicatrix. *A–A* and *B–B* are the major and minor diameters of the ellipse and so represent the extinction directions of the mineral section. *C–C* and *C′–C′* represent the intersections of the two circular sections of the indicatrix with this elliptical section. As these lines are diameters of equal circles they must be equal in length and it therefore follows from the geometrical nature of an ellipse that the angles *AOC* and *AOC′* are equal. Let the line *P–P* represent the intersection with this elliptical section of a plane in which lie the normal to the section and one of the optic axes. Since this plane includes an optic axis it must be perpendicular to the circular section of the indicatrix of which the line *C′–C′* is a diameter. Also since this plane includes the normal to the elliptical section under consideration it must be at right angles to the latter plane. Under these conditions it is obvious that the lines *P–P* and *C′–C′* in Fig. 579 must be at right angles to each other. In the same way it can be proved that the lines *P′–P′* and *C–C* are also at right angles to each other. Since the angles *AOC* and *AOC′* are equal and the angles *POC′* and *P′OC* are also equal it follows that the angles *AOP* and *AOP′* are likewise equal. In other words the lines *A–A* and *B–B* representing the directions of extinction of the section bisect the angles made by the traces upon the section of the two planes which respectively pass through each optic axis and the normal to the section. This fact will be made use of later, see Art. **407,** in explaining the characters of the biaxial interference figure.

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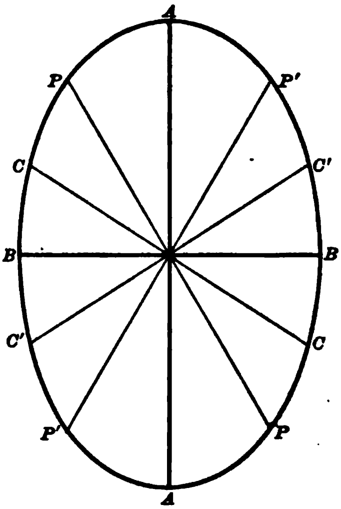

398. Primary and Secondary Optic Axes. — It has already been stated (Art. 397) that there are two directions, namely, those normal to the circular cross sections of the indicatrix (SS, $S'S'$, Fig. 577) in which all light is propagated with uniform velocity. Hence in these directions there can be no double refraction within a crystal; nor is there when the ray emerges. These two directions bear so close an analogy to the optic axes of a uniaxial crystal that they are also called *optic axes*, and the crystals here considered are hence named *biaxial*. In Fig. 575, which represents a cross section of the wave-surfaces in the plane of the X and Z directions, these optic axes have the direction SS, $S'S'$ normal to the tangent planes tt, $t't'$, and the direction of the external wave is given by the normal $S\sigma$ (Fig. 580).

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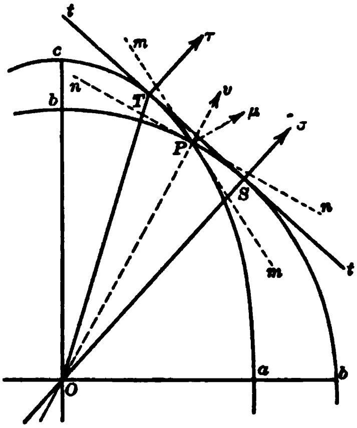

Properly speaking the directions mentioned are those of the *primary optic axes*, for there are also two other somewhat analogous directions, PP, $P'P'$, of Fig. 575, called for sake of distinction the *secondary optic axes*. The properties of the latter directions are obvious from the following considerations.

In the section of the wave-surface shown in Fig. 575 (also enlarged, in Fig. 580), corresponding to the axial plane XZ, it is seen that the circle with radius $\frac{1}{\beta}$ intersects the ellipse whose major and minor axes are $\frac{1}{\alpha}$ and $\frac{1}{\gamma}$ in the four points P, P, P', P'. Corresponding to these directions the velocity of propagation is obviously the same for both rays. Hence within the crystal these rays travel together without double refraction. Since, however, there is no common wave-front for these two rays (for the tangent for one ray is represented by mm and for the other by nn, Fig. 580) they do suffer double refraction on emerging; in fact, two external light-waves are formed whose directions are given by the normals $P\mu$ and $P\nu$. These directions, PP, $P'P'$, therefore, have a relatively minor interest, and whenever, in the pages following, optic axes are spoken of, they are always the *primary* optic axes, that is, those having the directions SS, $S'S'$ (Fig. 575), or OS, Fig. 580. In practice, however, as remarked in the next article, the angular variation between the two sets of axes is usually very small, perhaps 1° or less.

399. Interior and Exterior Conical Refraction. — The tangent plane to the wave-surface drawn normal to the line OS through the point S (Fig. 580) may be shown to meet it in a small circle on whose circumference lie the points S and T. This circle is the base of the interior cone of rays SOT, whose remarkable properties will be briefly hinted at. If a section of a biaxial crystal be cut with its faces normal to OS, those parallel rays belonging to a cylinder having this circle as its base, incident upon it from without, will be propagated within as the cone SOT. Conversely, rays from within corresponding in position to the surface of this cone will emerge *parallel* and form a circular cylinder. This phenomenon is called *interior conical refraction*.

On the other hand, if a section be cut with its faces normal to OP, those rays having the direction of the surface of a cone formed by perpendiculars to mm and nn will be propagated within parallel to OP, and emerging on the other surface form without a similar cone on the other side. This phenomenon is called *exterior conical refraction*.

In the various figures given (573–580) the relations are much exaggerated for the sake of clearness; in practice the relatively small difference between the indices of refraction α and γ makes this cone of small angular size, rarely over 2°.

400. Optic Axial Angle. Bisectrices. Positive and Negative Biaxial Crystals. — The optic axes always lie in the plane of the X and Z optical directions; this plane is called the optic axial plane (or, briefly, ax. pl.). It is obvious from a consideration of the indicatrix ellipsoid that the position of its circular sections and consequently of the optic axes normal to them, will vary with a variation in the relative values of the indices of refraction. As already stated the index β is not an arithmetical mean between α and γ but may at times be nearer to α than to γ or the reverse. As these relations change, the shape of the indicatrix and the position of its circular sections and the angle between the optic axes will also change. The mathematical relations between the optic axial angle and the principle refractive indices are given in the next article. From the above it is obvious that for certain relative values of the refractive indices, the optic angle must be 90°.* Such a case, however, is rarely observed and when it occurs it is true for light of a certain color † (wave-length) only and not for others.

The X and Z optical directions bisect the angles between the optic axes and are therefore known as *bisectrices*. The one that bisects the acute axial angle is called the *acute bisectrix* (or Bx_a) while the one bisecting the obtuse angle is the *obtuse bisectrix* (or Bx_o). If the word *bisectrix* is used alone without special qualification it is always to be understood as referring to the acute bisectrix.

Either X or Z may be the acute bisectrix. If X is the acute bisectrix the substance is said to be *optically negative*, while if Z is the acute bisectrix it is *optically positive*.

Roughly expressed, the optic axes will lie nearer to Z than to X — that is, Z will be the bisectrix — when the value of the intermediate index, β, is nearer to that of α than to that of γ. It is obvious (cf. Fig. 575) that in this case, as the angle diminishes and becomes nearly equal to zero, the form of the ellipsoid then approaches that of the prolate spheroid of the positive uniaxial crystal as its limit (Fig. 557, p. 256); this shows the appropriateness of the + sign here used.

On the other hand, the optic axes will lie nearer to X than to Z — that is, X will be the bisectrix — if the value of the mean index β is nearer to that of γ than to that of α. Such a crystal, for which $Bx_a = X$, is called *optically negative*. In this case the smaller the angle the more the ellipsoid approaches the oblate spheroid of the negative uniaxial crystal (Fig. 556, p. 256).

The following are a few examples of positive and negative biaxial crystals:

Positive (+).	Negative (−).
Sulphur.	Aragonite.
Enstatite.	Hypersthene.
Topaz.	Muscovite.
Barite.	Orthoclase.
Chrysolite.	Epidote.
Albite.	Axinite.

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[*] The axial angle will equal 90° when the indices satisfy the following equation:

$$\frac{1}{\alpha^2} - \frac{1}{\beta^2} = \frac{1}{\beta^2} - \frac{1}{\gamma^2}.$$

[†] For danburite axial angle = 89° 14′ for green (thallium) and 90° 14′ for blue ($CuSO_4$).

401. Relation of the Axial Angle to the Refractive Indices. — If in a given case the values of α, β, and γ are known, the value of the interior optic axial angle known as 2V; see also Art. 408, can be calculated from them by the following formulas:

$$\cos^2 V = \frac{\frac{1}{\beta^2} - \frac{1}{\gamma^2}}{\frac{1}{\alpha^2} - \frac{1}{\gamma^2}} \quad \text{or} \quad \tan^2 V = \frac{\frac{1}{\alpha^2} - \frac{1}{\beta^2}}{\frac{1}{\beta^2} - \frac{1}{\gamma^2}}.$$

Examination of Biaxial Crystals in Polarized Light

402. Sections in Parallel Polarized Light with Crossed Nicols.

Interference Colors. Thin sections of biaxial crystals when examined between crossed nicols in general show some interference color. This color will depend upon the following factors: *the thickness of the section*, — the thicker the section the higher the order of color; *the birefringence of the substance*, — the higher the birefringence (*i.e.*, the greater the difference between the values of α and γ) the higher the order of color; *the optical orientation of the section*, — in general, the nearer the section comes to being parallel to the optic axial plane, in which lie the vibration directions of the fastest and slowest rays, the higher will be its birefringence and the order of its interference color.

Extinction Directions. A section which, in general, is colored will show during a complete revolution on the microscope stage four positions at 90° intervals in which it appears dark. These are the positions of extinction, or are those positions in which the vibration planes of the section coincide with those of the nicols. When the directions of extinction of a section are parallel or at right angles to a crystallographic axis or to the trace, upon the section, of a crystallographic axial plane it is said to show *parallel extinction*. If the extinction directions are not parallel to these crystallographic directions the extinction is said to be *inclined*.

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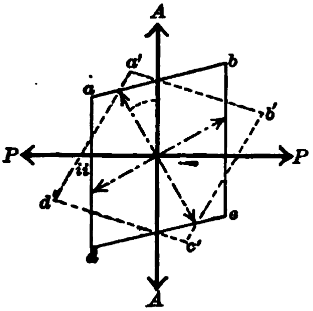

For example, in Fig. 581, let the two larger rectangular arrows represent the vibration directions for the two nicols, and between which suppose a section of a biaxial crystal, *abcd*, to be placed so that one edge of a known crystallographic plane coincides with the direction of one of these lines. The vibration directions of the section are indicated by the dotted arrows and as in this position of the section these directions do not coincide with the vibration directions of the nicols the section will appear light. The section will have to be turned to the position *a'b'c'd'* in order to achieve this coincidence and so bring about extinction. The angle (indicated in the figure) which it has been necessary to revolve the plate to obtain the effect described, is the angle which one of the vibration directions in the given plate makes with the given crystallographic edge *ad*; it is called the *extinction angle*.

403. Measurement of the Extinction Angle. — It frequently becomes important to measure as accurately as possible the extinction angle of a section. This is most commonly done with a microscope which is provided with a revolving stage having a graduated circle for measuring angles of rotation. In order to measure an extinction angle it is of course necessary to be able to locate in the section some definite crystallographic direction. This is usually provided by some crystal outline or cleavage crack. This crystallographic direction is brought parallel to one of the cross-hairs of the microscope and the angular position of the microscope stage noted. Then the stage is rotated until the section shows its maximum darkness. The angle between these two positions is the angle of extinction desired. The difficulty in the measurement lies in the accurate determination of the position of maximum extinction. Frequently it is possible to rotate the microscope stage through an arc of one to two degrees without any appreciable brightening of the field. It will help in determining the point of maximum extinction if the plate is turned beyond the point of extinction until the first faint illumination is observed and then back in the other direction until the same strength of illumination occurs. The point half way between these two positions should be very close to the point desired. The measurements should be repeated a number of times and the average taken. It is also advisable to make the measurements on both sides of the position of the crystallographic direction. The illumination in most cases had better be in the monochromatic sodium-light.

Various devices are used at times in order to increase the accuracy with which the position of maximum extinction can be determined.* The sensitive tint is sometimes used for this purpose. If this is inserted in the diagonal slot of the microscope tube below the analyzer the field will be uniformly colored red of the first order when the section on the microscope stage is at the position of extinction. But if the section is turned, even very slightly, from this position it will also affect the light and change the interference color observed. The sensitive tint in specially favorable cases can be used in this way to advantage but it has been shown that in the majority of cases its use does not materially increase the accuracy of the measurements.

The power of quartz plates cut normal to the vertical crystallographic axis to rotate the plane of polarization of light (see Art. **394**) is used in other devices to increase the accuracy of the measurement of the angle of extinction. The *Bertrand ocular* contains four such sectors of quartz; two of these placed diagonally opposite to each other are from a right-handed quartz crystal while the other two are from a left-handed crystal. This ocular is inserted in the microscope tube in place of the regular ocular; the analyzer is pushed out of the microscope tube and a nicol prism mounted in an appropriate holder is placed over the ocular. If this upper nicol is turned about in various positions it will be noted that, in general, opposite quadrants of the field are colored alike but differ in color from the adjacent quadrants, see Fig. 582. But when the plane of the cap nicol is exactly at right angles to the plane of the polarizer below all four quadrants show the same color. If a double refracting mineral be placed on the stage of the microscope with its vibration directions parallel to those of the nicols, since in this position it has no birefringent effect upon the light, the field will still remain uniformly colored. But if the section is turned from its

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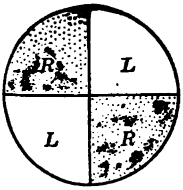

Bertrand Ocular

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* Detailed descriptions of these various devices with comment on their accuracy are given by F. E. Wright in The Methods of Petrographic-Microscopic Research.

position of extinction its birefringent effect is added to that of the two opposite quadrants of the ocular and subtracted from that of the remaining two. Consequently adjacent quadrants become differently colored. A very slight rotation of the section is sufficient to produce an appreciable effect.

Another microscope accessory using the same principle as the Bertrand ocular is the so-called *bi-quartz wedge plate* described by Wright. This consists of two adjacent plates of quartz cut normal to the *c* crystal axis, one from a left-handed and the other from a right-handed crystal. Above these are placed two wedges of quartz, a right-handed wedge above the left-handed plate, etc. At the point where the wedge is equal in thickness to the plate beneath there will be zero rotation of the light and between crossed nicols this will produce a dark line across the field. As the distance increases from this point the amount of rotation of the light increases equally but in opposite directions on either side of the central dividing line of the plate. Both halves of the plate will be equally illuminated if the mineral section is in the position of extinction, but if the latter is turned so that it adds or subtracts its birefringent effect to that of the quartz plate the two halves become differently illuminated. By moving the plate in or out a position can be found where this change in illumination is most marked. This quartz plate is used with a special ocular provided with a slot in such a position that the quartz plate may be introduced into the microscope tube at the focal plane of the ocular and with the medial line of the plate parallel to the plane of vibration of the polarizer. A cap nicol is used above the ocular.

404. Determination of the Birefringence with the Microscope. — The value of the maximum birefringence ($\gamma - \alpha$) is obviously given at once when the refractive indices are known. It can be approximately estimated for a section of proper orientation and of measured thickness by noting the interference-color as described in Art. **347.**

405. Determination of the Relative Refractive Power. — The relative refractive power of the two vibration-directions in a thin section is readily determined with the microscope (in parallel polarized light) by the method of compensation. This is applicable to any section, whatever its orientation and whether uniaxial or biaxial. The methods employed have already been described in Art **348.**

A crystal-section is said to have *positive elongation* if its direction of extension approximately coincides with the ether-axis Z; if with X the elongation is *negative.* The same terms are also used, in general, according to the relative refractive power of the two directions.

406. Determination of the Indices of Refraction of a Biaxial Mineral. — The indices of refraction of a biaxial mineral are determined by the same methods as outlined previously, see Art. **327,** the only modification introduced being necessitated by the fact that three principal indices, α, β and γ, are to be determined.

Measurement of the Angles of Refraction by Means of Prisms. Two or three prisms must be used to determine the three indices. If three prisms are used they are cut so that their edges are parallel respectively to the X, Y, and Z directions of the mineral. In the case of an orthorhombic mineral, in which these directions are parallel to the directions of the three crystallographic axes, the prism edges would have to be respectively parallel to the a, b, and c crystal axes. In crystals of the monoclinic and triclinic systems the proper orientation of the three prisms is a matter of considerable difficulty.

Each such prism will yield two refracted and polarized rays but only the one whose light has its vibrations parallel to the edge of the prism (to be determined by the use of a nicol) is considered. In certain cases all three indices may be obtained from two prisms. If one prism is cut so that not only is its edge parallel to one of the directions X, Y, and Z but so that its medial plane contains not only this direction but one other, then by the use of the method of minimum deviation an index may be determined from each of the two refracted rays. Or with a small angle prism cut so that one of its faces contains two of these directions the corresponding two indices may be determined when the method of perpendicular incidence is used upon this face. In making these measurements it is important to note the crystallographic directions parallel to which the different rays vibrate. In this way the optical orientation in respect to the crystallographic directions can be determined.

Method of Total Reflection. The method of total reflection for determining the indices of refraction of a biaxial mineral has the obvious advantage that only polished plates of the mineral are required instead of carefully orientated prisms. In general, the plane surface of a plate will give with the total refractometer two boundaries of total reflection. Both of these shadows move when the section is rotated. Four readings should be taken corresponding to the maximum and minimum positions of each boundary. The largest and smallest angles read will give on calculation the values for the greatest and least indices of refraction, *i.e.*, γ and α. The mean index of refraction, β, can be derived from one of the other measurements. There are certain more or less complicated methods by which these two intermediate readings can be tested in order to prove which is the correct one for the index β. It is commonly simpler to make use of another plate having a different crystallographic orientation. It will be found that in the second plate one of the intermediate angles corresponds with one already observed on the first plate while the second angle shows no such correspondence. The angle that is common to the two plates is the one desired. If the plate is orientated so that its plane contains two of the three optical directions, X, Y and Z, all three indices can be obtained easily from the single plate. In this case one of the boundaries of total reflection is stationary for different positions of the plate. This corresponds to the ray whose vibrations are normal to the surface of the plate. The other boundary will vary its position as the plate is rotated and yield at its maximum and minimum positions the angles corresponding to the other two indices of refraction.

407. Sections of Biaxial Crystals in Convergent Polarized Light. — In general, sections of biaxial crystals when examined in convergent polarized light show interference figures. The best and most symmetrical figures are to be observed when the section has been cut perpendicular to a bisectrix, and preferably to the acute bisectrix. If such a section is examined under the conditions described in the case of uniaxial crystals, see Art. **389**, figures similar to those shown in Fig. 583 will be observed. When the axial plane, *i.e.*, the plane including the two optic axes, lies parallel to the direction of vibration of the polarizer the figure is similar to that of Fig. 583, A. When these two directions are inclined at a 45° angle the figure is like that shown in Fig. 583, B.

First consider the interference figure in the parallel position, Fig. 583, A and when viewed in monochromatic light. It consists of two black bars that form a cross somewhat similar to the cross of a uniaxial figure. The horizontal bar is thinner and better defined than the vertical one. About two points on the horizontal bar, there will be observed a concentric series of dark elliptical curves which, as they enlarge, coalesce, forming first a figure eight and then a double curve. As the section is rotated on the microscope or polariscope stage, the black bars forming the cross separate at the center and curve across the field pivoting on these points until at the 45° position, Fig. 583, B, they form the two arms of a hyperbola.

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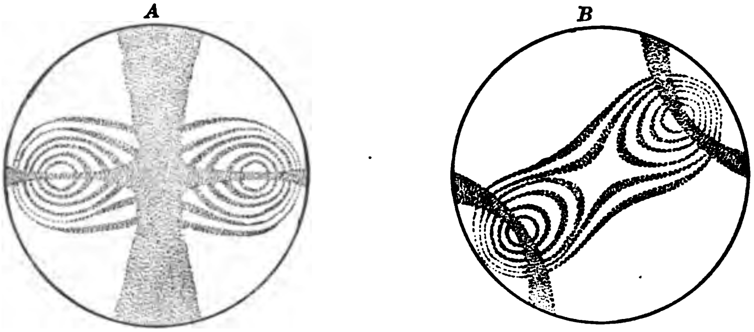

Biaxial Interference Figures

A biaxial mineral has two directions, the directions of the optic axes, along which light travels with no double refraction. At these points there would be no birefringence and consequently dark spots would result. As the paths of the light rays become inclined to the directions of the optic axes the light suffers double refraction and in increasing degree as the amount of inclination becomes greater. Consequently at short distances away from these points the light must be refracted into two rays which have a difference of phase of one wave-length for a certain colored light, the yellow of the sodium flame in this case. The result will be extinguishment at such points. The assemblage of all points where the difference of phase equals one wave-length yields the first dark elliptical-like curve, called a lemniscate, shown in the figure. Further out will be found curves embracing the points where the difference of phase is two wave-lengths, three wave-lengths, etc.

If the interference figure is viewed in daylight instead of the monochromatic light the black curves will be replaced by colored ones. Each colored curve is produced by the elimination from the white light of some particular wave-length of light on account of the interference explained above.

The convergent bundle of light rays that pass through the section will each have its own particular plane of vibration. The directions of the planes of vibration for light emerging from the section at any given point can be found, as explained in Art. **397**, by bisecting the angles made by two lines connecting this point with the two points of emergence of the optic axes. Fig. 584 shows how the direction of vibration of the two rays emerging from given points can be obtained in this way. These directions of vibration vary over the field and consequently some of them must always be parallel or very nearly so to the planes of vibration of the nicol prisms. When this happens the light is extinguished and darkness results. This explains the formation of the black bars of the interference figure. Fig. 585 shows the bars in the crossed position and Fig. 586 when separated into the hyperbola arms. As the section is turned the vibration directions of new points successively become parallel to the planes of the nicols and so the dark bars sweep and curve across the field.

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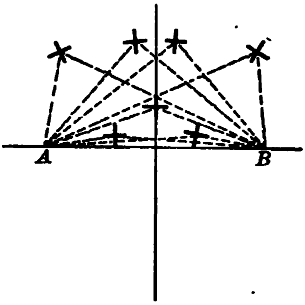

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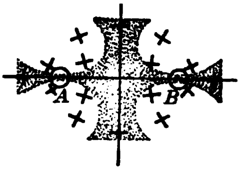

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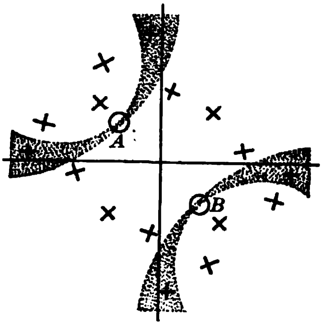

With a thick section or one of a mineral of high birefringence, the number of colored curves (when the figure is viewed in daylight) is greater than with a thinner section or one with low birefringence. An instructive experiment can be made by noting the changes in the interference figure obtained from a section of muscovite as the mineral is cleaved into thinner and thinner sheets. In most rock sections the minerals are ground so thin that their interference figures do not show any colored curves but rather only the dark hyperbola bars.

The biaxial interference figure varies in appearance with the change in the angle between the optic axes. Where this angle is very small the figure becomes practically the same as that of a uniaxial crystal. Where this angle becomes greater than 60° the points of the emergence of the optic axes will commonly lie outside the microscope field. In the latter case the hyperbola arms will appear as the section is brought into the parallel position, form a cross, and then as the section is further revolved will curve out of the field again. The larger the axial angle the more rapidly will the bars disappear from the field. A comparative measurement of the axial angles of two minerals can be made by noting the angle through which the microscope stage has to be turned in order to cause the bars to leave the field. The system of lenses must be kept the same for the two experiments. Or by experimenting with various minerals with known axial angles a scale could be derived for a certain microscope and system of lenses so that the axial angle of any other mineral could be approximately measured in this way.

A symmetrical interference figure may also be obtained from a section cut perpendicular to the obtuse bisectrix. In general, the obtuse axial angle is considerably larger than the acute angle and the interference figure will differ therefore in this respect from that obtained from the section cut perpendicular to the acute bisectrix.

It is important to be able to recognize the biaxial interference figures which are obtained from inclined sections. They are chiefly characterized by the fact that the hyperbola bars curve as they cross the field. This characteristic distinguishes the figure from an eccentric uniaxial figure in which the bars of the cross move in straight lines as the section is turned. Fig. 587 shows in the row *A* a series illustrating the appearance in different positions of the figure when the section is slightly inclined to the bisectrix. In row *B*, a series where the section is cut perpendicular to an optic axis and the hyperbola bar revolves in the field as upon a pivot. In this case the bar curves with its convex side toward the acute bisectrix. If the axial angle was 90° there would be no distinction between acute and obtuse bisectrices and the bar would then revolve as a straight line. Therefore such a figure indicates by the amount of the curvature of the bar the size of the axial angle. The figures given by planes cut nearly normal to an optic axis are often of great use in the optical examination of a mineral. Sections which will furnish them are easily found by noting those sections of the mineral that remain dark or nearly so during their rotation between crossed nicols. If the single bar shown in such a figure exhibits a decided curvature it indicates that the direction of the acute bisectrix is not very much inclined to the plane of the section and consequently its character, whether *X* or *Z*, can be determined by noting the character of that extinction direction which symmetrically bisects the curve. From this observation the positive or negative character of the mineral can be determined. In row *C*, Fig. 587, is shown a series of figures where the section has a still greater inclination. A section cut parallel to the axial plane does not give a decisive interference figure. Often it is difficult to distinguish it from the figure obtained from a section cut parallel to the optic axis of a uniaxial mineral, see Art. 392. It should be pointed out that, while in general the interference figures of these two optical classes are to be clearly distinguished from each other, cases may arise in which such differentiation is difficult if not impossible.

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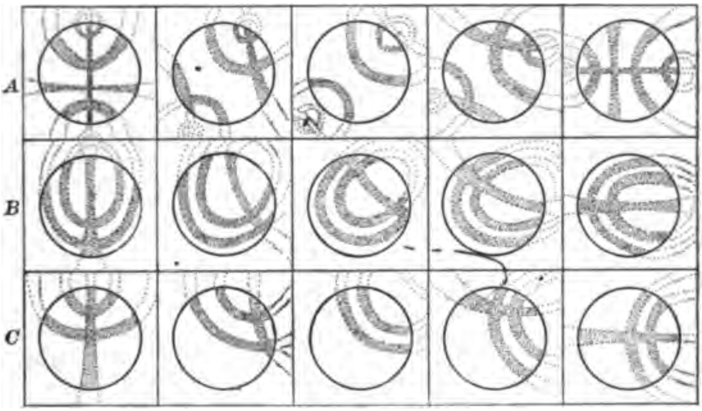
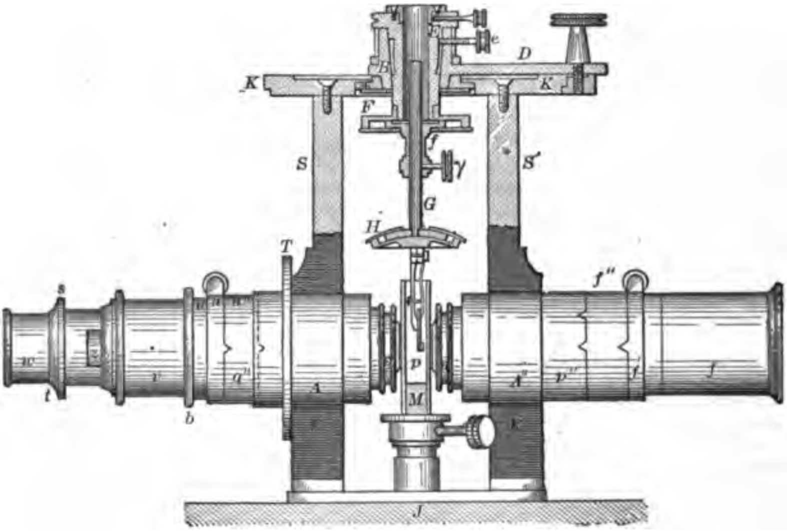


Eccentric Biaxial Interference Figures

408. Measurement of the Axial Angle. — The determination of the angle made by the optic axes is most accurately accomplished by use of the instrument shown in Fig. 588. The section of the crystal, cut at right angles to the bisectrix, is held in the pincers at *p*, with the plane of the axes *horizontal*, and making an angle of 45° with the vibration-plane of the nicols. There is a cross-wire in the focus of the eyepiece, and as the pincers holding the section are turned by the screw at the top (here omitted) one of the axes, that is, one black hyperbola, is brought in coincidence with the vertical cross-wire, and then, by a further revolution, the second. The angle which the section has been turned from one axis to the second, as read off at the vernier on the graduated circle above, is the *apparent* angle for the axes of the given crystal as seen in the air ($aca = 2E$, Fig. 589). It is only the *apparent* angle, for, on passing from the section of the crystal to the air, the true axial angle is more or less increased, according to the refractive power of the given crystal. The relation between the real interior angle and the measured angle is given below.

588

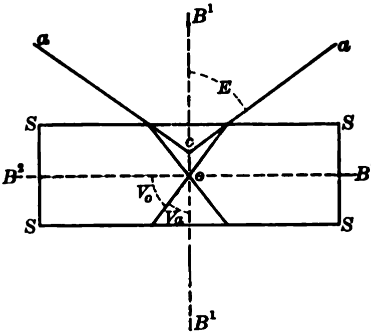


Axial Angle Apparatus

If the axial angle is large, the axes may suffer total reflection. In this case some oil or liquid with a high refractive power is interposed so that the axes will no longer be totally reflected but emerge into the liquid and thence into the air. In the instrument described a small receptacle holding the oil is brought between the tubes, as seen in the figure, and the pincers holding the section are immersed in this and the angle measured as before.

In the majority of cases it is only the acute axial angle that it is practicable to measure; but sometimes, especially when oil (or other liquid) is made use of, the obtuse angle can also be determined from a second section normal to the obtuse bisectrix.

589



Measurement of Axial Angle

If E = the apparent semi-acute axial angle in air (Fig. 589),
H_a = " " " " " in oil,
H_o = " " semi-obtuse angle in oil,
V_a = the (real or interior) semi-acute angle,

V_o = the (real or interior) semi-obtuse angle,
n = refractive index for the oil or other medium,
β = the mean refractive index for the given crystallized substance,
the following simple relations connect the various quantities mentioned:

$$\sin E = \beta \sin V_a;\ \sin E = n \sin H_a;\ \sin V_a = \frac{n}{\beta} \sin H_a;\ \sin V_o = \frac{n}{\beta} \sin H_o.$$

These formulas give the true interior angle ($2V$) from the measured apparent angle in air ($2E$) or in oil ($2H$) when the mean refractive index (β) is known.

409. Axial Angle Measured with the Microscope. — Approximate measurements of the axial angle may be made by various methods with the microscope. In most cases some sort of a micrometer ocular is used which contains an engraved scale. By means of this scale the distance between the points of emergence of the optic axes can be determined. Mallard * showed that the distance of any point from the center of the interference figure as observed in the microscope is very closely the same as the sine of the angle which the ray emerging at this point makes with the axis of the microscope. The Mallard equation for the derivation of the axial angle is $D = K \sin E$, in which D equals one half the measured distance between the optic axes and K a constant which varies with the microscope and the system of lenses used. K for a given set of lenses may be determined by observing the interference figures derived from plates of minerals with known axial angles and then substituting the values for D and E in the above equation. The angular values of the divisions on the micrometer scale of the ocular may also be determined directly by the use of an instrument known as the apertometer. The measurement of an axial angle by means of the microscope is naturally most easily accomplished when the points of emergence of both optic axes are visible in the field. It is possible, however, by various ingenious methods to determine its value when only one optic axis is in view. These methods are too complicated and too seldom used to be explained here and the reader is referred to the text books on the methods of petrographic investigation for their details.†

410. Determination of the Optical Character of a Biaxial Mineral from Its Interference Figure. Use of the Quartz Wedge. — If the section is turned until its interference figure is in the 45° position and then the quartz wedge inserted above the section through the 45° slot in the microscope tube the vibration directions of the section along a line that joins the optical axes and a line at right angles to this through the center of the figure will be parallel to the vibration directions of the quartz-wedge. Under these circumstances the effect of the introduction of the quartz wedge will be to gradually increase or diminish along these lines the birefringence due to the section alone. If the directions of vibration of the faster and slower rays in the quartz coincide with the vibration directions of the similar rays in the section, the total birefringence will be increased and the effect upon the interference figure will be as if the section had been thickened. Complete interference will take place with rays of less obliquity and the colored curves will be drawn closer together. They will move, as the quartz wedge is pushed in over the section, as indicated by the arrows shown in Fig. 590. On the other hand, if the quartz wedge is so placed that its optical orientation is opposed to that of the section, the effect will be the same as if the section was being gradually thinned. The colored rings about the points of the optic axes will expand until they meet in the center as a figure eight and then grow outwards as a continuous curve. The directions of their movements are shown by the arrows in Fig. 591. Therefore, by knowing the optical orientation of the quartz-wedge and noting the

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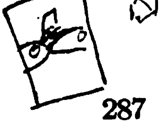
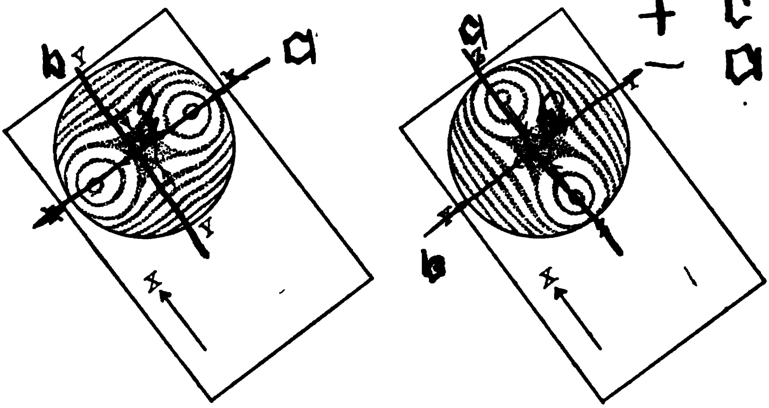
* Bull. Soc. Min., 5, 7787, 1882.

† See especially Wright, The Methods of Petrographic Microscopic Research, and Johannsen, Manual of Petrographic Methods.



effect of its introduction over a section upon the interference figure, it is possible to determine the relative character of the two important extinction directions of the sections; that is, to determine whether the ray vibrating in the plane which includes the optic axes is faster or slower than the one which vibrates in the plane at right angles to this direction.

In the case of a positive mineral the acute bisectrix, which in a symmetrical interference figure is the direction normal to the section, is the direction *Z*. Consequently the direction of the line in the section which passes through the points of emergence of the two optic axes is the direction of the obtuse bisectrix, or in this case the direction *X*. The direction *Y* then will lie in the plane of the section and at right angles to the line joining the points of emergence of the optic axes. In the case, therefore, of a positive



+ c is bxa
− a is bxa

Determination of Optical Character of Biaxial Mineral with Quartz Wedge

mineral, the faster ray has its vibrations lying in the optical axial plane With a negative mineral the direction *X* becomes the acute bisectrix and will be normal to the section, while the direction *Z* will lie in the section along the line connecting the points of emergence of the optic axes. With a negative mineral, therefore, the vibration direction which lies in the optical axial plane is of the slower ray. By finding, therefore, the relative character of these two vibration directions the optical character of the mineral is determined. The effects produced by an interference figure which is perpendicular to an obtuse bisectrix would be exactly opposite to those described above. It is imperative, therefore, that the positions of the two bisectrices be definitely known. With sections that are very thin or with minerals of low birefringence the interference figure may show only the black hyperbolas without any colored rings. In such cases, frequently the introduction of the quartz wedge in such a position that its optical orientation is parallel to that of the section will suffice to so thicken the section in effect as to cause the appearance of colored rings. Further, with such sections it is possible to establish the directions in the section that are parallel and at right angles to the trace upon the section of the optical axial plane. Then, by use of the sensitive tint, when the convergent lens has been removed the character of the vibrations parallel to these two directions is easily determined.

411. Absorption Phenomena of Biaxial Crystals. Pleochroism. — Colored biaxial crystals like similar uniaxial crystals may show different degrees or kinds of absorption of the light passing through them depending upon the direction of vibration of the light. In biaxial crystals there may be three different degrees of absorption corresponding to three different directions of vibration lying at right angles to each other. In general, these directions coincide with the optical directions X, Y, and Z. Variations from this parallelism may be observed, however, in crystals of the monoclinic and triclinic systems. It is customary, however, to describe the absorption as it is observed parallel to the directions X, Y, and Z. If light vibrating parallel to X is the most absorbed and light vibrating parallel to Z is the least absorbed these facts are expressed as $X > Y > Z$. There are various other possibilities, such as $X > Y = Z$, $Z > X > Y$, etc. Further, according to the kind of selective absorption, the crystal may show distinctly different colors for light vibrating in the different directions, or in general show *pleochroism*. The character of the pleochroism is stated by giving the colors corresponding to the vibrations parallel to X, Y, and Z. For instance, in the case of *riebeckite*, X = deep blue, Y = light blue, Z = yellow-green. In order to investigate the absorption properties of a biaxial crystal at least two sections must be obtained in which will lie the directions X, Y, and Z. These sections are examined on the stage of the polariscope or microscope without the upper nicol. They will show as they are rotated upon the stage variations in absorption and in color as the light passing through them vibrates parallel to first one and then the other of their vibration directions. See the discussion of dichroism in uniaxial minerals, Art. **393**.

When a section cut normal to an optic axis of a crystal characterized by a high degree of color-absorption is examined by the eye alone (or with the microscope) in strongly converging light, it often shows the so-called *epoptic figures*, *polarization-brushes*, or *houppes* somewhat resembling the ordinary axial interference-figures. This is true of andalusite, epidote, iolite, also tourmaline, etc. A cleavage section of epidote $\parallel c(001)$ held close to the eye and looked through to a bright sky shows the polarization-brushes, here brown on a green ground. These figures are caused by the light being differently absorbed as it passes through the section with different degrees of inclination.

In certain minerals small circular or elliptical spots may be observed in which the pleochroism is stronger than in the surrounding mineral. These are commonly spoken of as *pleochroic halos*. They are found to surround minute inclusions of some other mineral. There have been many diverse theories to account for these "halos" but recently it has been shown that they are probably due to some radioactive property of the inclosed crystal. Pleochroic halos have been observed in biotite, iolite, andalusite, pyroxene, hornblende, tourmaline, etc., while the included crystals belong to allanite, rutile, titanite, zircon, apatite, etc.

Special Optical Characters of Orthorhombic Crystals

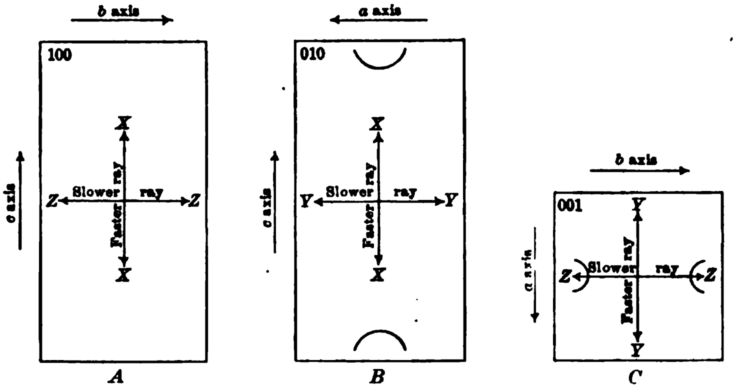
412. Position of the Ether-axis. — In the ORTHORHOMBIC SYSTEM, in accordance with the symmetry of the crystallization, the three axes of the indicatrix, that is, the directions X, Y, and Z, *coincide* with the three crystallographic axes, and the three crystallographic axial planes of symmetry correspond to the planes of symmetry of the ellipsoid. Further than this, there is no immediate relation between the two sets of axes in respect to magnitude, for the reason that, as has been stated, the choice of the crystallographic axes is arbitrary so far as relative length and position are concerned, and hence made, in most cases, without reference to the optical character.

Sections of an orthorhombic crystal parallel to a pinacoid plane ($a(100)$, $b(010)$, or $c(001)$) appear dark between crossed nicols, when the axial directions coincide with the vibration-planes of the nicols; in other words, such sections show parallel extinction.

The same is true of all sections that are parallel to one of the three crystallographic axes, *i.e.*, sections lying in the prism, macrodome and brachydome zones. Sections, however, that are inclined to all three crystallographic axes, *i.e.*, pyramidal sections, will show inclined extinction.

413. Determination of the Plane of the Optic Axes. — The plane of the *optic axes*, that is, the plane including the directions *X* and *Z*, must be parallel to one of the three pinacoids. Further, the acute bisectrix must be normal to one of the two pinacoids that are at right angles to the optic axial plane while the obtuse bisectrix is normal to the other such pinacoid. The optical orientation, *i.e.*, the relation between the principal optical and crystallographic directions, can be easily determined by the examination of sections of a crystal which are cut parallel to the three pinacoids. To illustrate by an example, let it be assumed that such sections of the mineral aragonite are available. These are represented in Fig. 592, *A*, *B*, and *C*. If the relative characters of the vibration directions of each section are determined it will be found that light vibrating parallel to the *c* axis in sections parallel to (100) and (010) is in both cases moving with the greater velocity, that light vibrating parallel to the *b* axis in (100) and (001) is in both cases the slower ray, and that light vibrating parallel to the *a* axis is the faster ray in (001) but the slower ray in (010). From this it is seen that the *a* axis must coincide with the direction of vibration of the ray having the intermediate velocity, or be the same as the optical direction *Y*. Also it follows that *c* axis = *X* and *b* axis = *Z*. The optic axial plane, therefore, since it must include *X* and *Z*, lies parallel to (100). If the sections parallel to (001) and (010) are examined in convergent light both will show biaxial interference figures with the points of emergence of the optic axes lying as illustrated in *B* and *C*, Fig. 592. The axial angle observed with the section parallel to (001) is much smaller than that obtained from (010). Consequently the acute bisectrix is normal to the base (001) and since it is the direction *X* the mineral is optically negative. These facts of optical orientation may be summarized in the statements: optically –, Ax. pl. || *a*(100), $\text{Bx}_a \perp c(001)$.

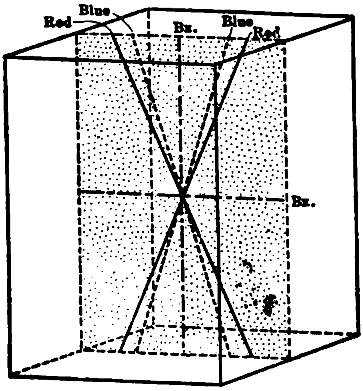
592



Optical Orientation of Aragonite

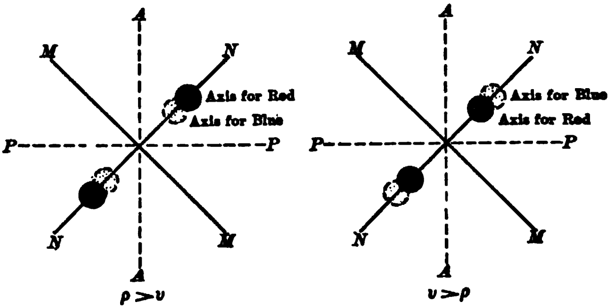
414. Dispersion of the Optic Axes in Orthorhombic Crystals. — In determining the indices of refraction of a crystal by means of the prism method it is to be noted that when the incident ray is of white light the refracted ray will in general show this white light dispersed into its primary colors. The amount of this dispersion is usually small but in certain substances becomes considerable. Obviously since the angle of refraction varies in this way with the different wave-lengths of light the indices of refraction will also vary. In biaxial minerals, as already stated, the optic axial angle is directly dependent upon the relative values of the three indices of refraction, α, β, and γ. As these indices may show considerable differences, depending upon the wave-length of the refracted ray, it follows that the optic axial angle will also vary with the color of the light used. In other words, the optic axes may be dispersed. Fig. 593 represents such a case in which the angle between the optic axes for red light is greater than that for blue. The opposite condition may hold, in which the angle for blue is greater than for red. From this it follows that the interference figure when observed in blue light will not exactly coincide with that produced by red light. The bisectrices of both figures will be the same but the position of the points where the optic axes emerge will be different and consequently the positions of the hyperbolas and lemniscate curves will also be different. In the case of orthorhombic crystals the dispersion will always be symmetrical to the two symmetry planes of the indicatrix that pass through the acute bisectrix, *i.e.*, the directions *M-M* and *N-N* in Figs. 594 and 595. This particular type of dispersion is said to be *Orthorhombic Dispersion*, in order to distinguish it from that observed in biaxial crystals of other systems. The two possible cases of orthorhombic dispersion are shown in Figs. 594 and 595. In expressing these two cases the Greek letters ρ (for red) and υ (for violet) are used. When the axes for red light are more dispersed than those for blue that fact is expressed as $\rho > \upsilon$ or in the reverse case it is $\rho < \upsilon$.

593



Orthorhombic Dispersion

594 595

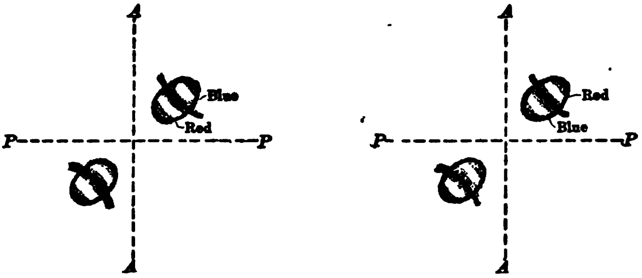


$\rho > \upsilon$ $\upsilon > \rho$

Orthorhombic Dispersion

In the majority of cases the effect produced upon the interference figure by the dispersion of the optic axes is too slight to be noted. In exceptional cases where the amount of dispersion is large the effects are clearly seen. The hyperbola bars, which are ordinarily black throughout, will, when the figure is observed in white light, be seen, near the center, to be bordered on one side by a red fringe and on the other by a blue one. The first one or two of the colored lemniscates will also be broadened out along the line joining the two optic axes. As already stated these changes in the appearance of the figure will always be symmetrical in respect to the traces of the two symmetry planes lying at right angles to each other. In the case, Fig. 594, where the axes for red light are farther apart than those for blue ($\rho > v$), the hyperbolas in the interference figure for the two different wave-lengths of light will not coincide and the ones where the red light is extinguished will be farther out than those for blue light. When red light is taken out of the white light, blue remains, and conversely when blue is subtracted the resultant color is red. Consequently in this case the hyperbola bars will be bordered on their concave sides by blue and on their convex sides by red, Fig. 596. In the other case, where $\rho < v$, the hyperbolas will be bordered on their concave sides by red and on their convex sides by blue, Fig. 597. In other words, if blue light shows at the larger angle it means that red light has been eliminated from these positions and the optic axes for red are more dispersed than those for blue, etc.

596 597



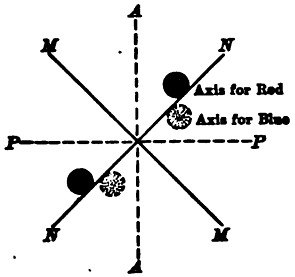
$\rho > v$ $v > \rho$

Orthorhombic Dispersion

Special Optical Characters of Monoclinic Crystals

415. Optical Orientation of Monoclinic Crystals. — In monoclinic crystals there is one axis of symmetry, the *b* crystallographic axis, and one plane of symmetry, the plane of the *a* and *c* crystallographic axes. These are the only crystallographic elements that are definitely fixed in position. One of the three chief optical directions, *X*, *Y*, or *Z*, is coincident with the *b* crystallographic axis, while the other two lie in the symmetry plane, (010), but not parallel to any crystal direction. There are obviously three possible cases. If *Y* coincides with the axis *b* (and this is apparently the most common case) the directions *X* and *Z* will lie in the crystal symmetry plane, which therefore becomes the optic axial plane. If *X* or *Z* coincides with the *b* axis the optic axial plane will be at right angles to (010) and either the acute or obtuse bisectrix will be normal to that plane. This clino-pinacoid of a monoclinic crystal is usually the best plane upon which to study its optical orientation. Fig. 598 represents such a section cleaved from an ordinary crystal of gypsum. The cleavages parallel to (100) and ($\bar{1}11$) will serve to give its crystallographic orientation. Examination of the section in convergent light fails to show a distinct interference figure, consequently it is to be assumed that the section itself is parallel to the optic axial plane and that the direction *Y* is imately perpendicular to the acute bisectrix) is symmetrical to the line *M–M* but unsymmetrical in respect to the line *N–N*. Fig. 604 shows the effect of horizontal dispersion upon the interference figure.

603



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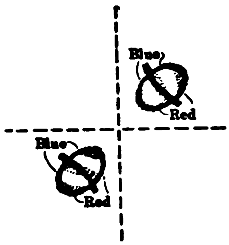
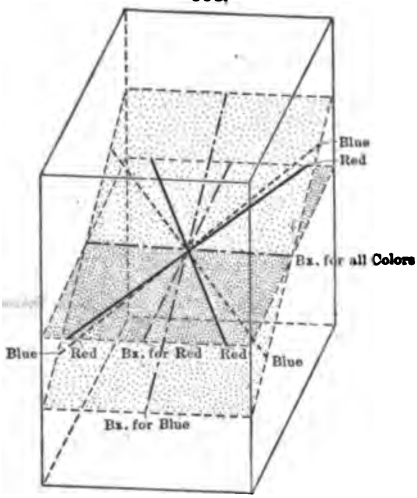


Horizontal Dispersion $\rho > v$

Case 3. *Crossed Dispersion.* In this case the crystallographic axis *b* coincides with the acute bisectrix, which may be either the *X* or *Z* direction depending upon the optical character of the crystal. In this case the direction of the acute bisectrix is fixed for light of all wave-lengths. The angle between the optic axes may vary and further the position of the axial planes for different wave-lengths may vary as long as they remain perpendicular to the crystallographic symmetry plane. A case of this sort is shown in Fig. 605. The points of emergence of the optic axes when $\rho > v$ for blue and red light might therefore be like that shown in Fig. 606. It will be seen that in this case the figure is symmetrical to neither the line *M–M* nor *N–N* but only to the central point of the figure, *i.e.*, the point of emergence of the acute bisectrix. Fig. 607 shows the effect of crossed dispersion upon the interference figure.

605



Crossed Dispersion

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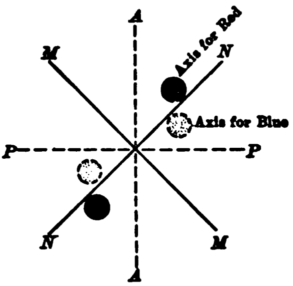

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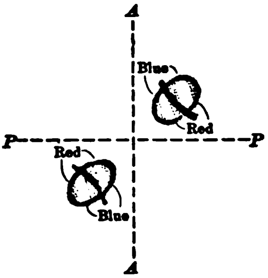

Crossed Dispersion $\rho > v$

Special Optical Characters of Triclinic Crystals

418. Optical Orientation of Triclinic Crystals. — The center of the optical ellipsoidal figure coincides with the center of the system of crystallographic axes but there is no further correspondence between optical and crystallographic directions.

419. Extinction in Triclinic Crystals. — Since there is no parallel relation existing between optical and crystallographic directions in triclinic crystals all sections will show inclined extinction.

420. Dispersion in Triclinic Crystals. — Because of the lack of coincidence between any optical and crystallographic direction in triclinic crystals it follows that the optic axes and bisectrices for different wave-lengths of light may be dispersed in any direction. Consequently the dispersion shown in an interference figure obtained from a triclinic crystal is irregular and without symmetry.

421. Suggestions as to Methods and Order of Optical Tests upon an Unknown Mineral. — *Preparation of Material.* The size and character of the fragments or section of a mineral to be studied will depend upon various circumstances. In the majority of cases it will probably be most convenient to crush the mineral into small uniform sized fragments. In other cases a cleavage flake of the mineral will serve, and under still other conditions it may be preferable to cut an unorientated or, better, an orientated section. For at least the preliminary examination small irregular fragments of varying orientation will most often be used. Take a few of these mineral grains and place them upon an object glass and immerse them either in Canada balsam or in some oil with known refractive index and cover with a piece of thin cover glass. In the majority of cases it will prove more expeditious and convenient to place the fragments in an oil.

Order of Optical Tests. Below is given a brief outline of the natural order of observations and tests to be made upon the mineral.

1. *Observations in plane polarized light without the upper nicol.*
   - *a.* Note color of mineral, whether uniform or not.
   - *b.* By rotating slide on microscope stage test for possible pleochroism. If the mineral exhibits pleochroism it cannot be isotropic. Connect as far as possible the directions of absorption with crystallographic directions.
   - *c.* Note crystal outline, if any; cleavage cracks, etc.
   - *d.* Note any inclusions, their shape and arrangement.
   - *e.* Index of refraction. Determine approximately the refractive index. Note character of relief and determine whether mineral has a higher or lower index than the medium in which it is immersed (see Art. **325**).
2. *Observations in plane polarized light with crossed nicols.*
   - *a.* If the section is dark between crossed nicols and remains so during the rotation of the stage the mineral is either isotropic or orientated perpendicular to an optic axis. In the latter case test as indicated below under 3*a*.
   - *b.* If the section is alternately light and dark during the rotation of the stage the mineral is anisotropic.
   - *c.* Note position of extinction directions. If they are inclined to some known crystallographic direction measure the angle of inclination.

d. Determine the relative character of the two vibration directions of the section (*i.e.*, the two extinction directions), as to which corresponds to the faster and which to the slower ray. Test to be made with quartz wedge or sensitive tint, see Art. **348.**

e. Find the grain showing the highest order of interference color and so approximately determine the strength of the mineral's birefringence.

f. By immersion in oils of known refractive indices determine as accurately as possible the range of the refractive indices shown by the mineral. It may be possible in connection with tests made under 3 to determine the values for certain of the principal refractive indices.

3. *Observations in convergent polarized light with crossed nicols.*

a. Note whether the mineral shows an interference figure, and if so whether it is uniaxial or biaxial.

b. If mineral is uniaxial determine the position of the optic axis in respect to the plane of the given section and if possible determine the positive or negative character of the mineral.

c. If the mineral is biaxial determine the position of the axial plane in respect to the section. Determine, if possible, the positive or negative character of the mineral. Obtain, if possible, an approximate idea as to the size of the axial angle. Note any evidences of dispersion.

Note. — In making the above tests it is helpful to keep, as far as possible, a graphic record of the results, something like that illustrated in Fig. 592.

422. Effect of Heat upon Optical Characters. — The general effects of heat upon crystals as regards expansion, etc., are spoken of later. It is convenient, however, to consider here, briefly, the changes produced by this means in the special optical characters. It is assumed that no alteration of the chemical composition takes place and no abnormal change in molecular structure. In general, the effect of a temperature change causes a change in the refractive indices. In the majority of cases the indices decrease in value with rise of temperature but in certain cases the reverse is true. It is consequently important in any exact statement of a refractive index to give the temperature at which it was determined. The particular facts for the different optical classes are as follows:

(1) *Isotropic* crystals remain isotropic at all temperatures. Crystals, however, which, like sodium chlorate ($NaClO_3$ of Class 5, p. 72), show circular polarization may have their rotatory power altered; in this substance it is increased by rise of temperature.

(2) *Uniaxial* crystals similarly remain uniaxial with rise or fall of temperature; the only change noted is a variation in the relative values of ω and ϵ, that is, in the strength of the double refraction. This increases, for example, with calcite and grows weaker with beryl and quartz. It is, further, interesting to note that the rotatory power of quartz increases with rise of temperature, but the relation for all parts of the spectrum remains sensibly the same.

(3) With *Biaxial crystals*, the effect of change of temperature varies with the system to which they belong.

The axial angle of biaxial crystals may be measured at any required temperature by the use of a metal air-bath. This is placed at *P* (Fig. 588) and extends beyond the instrument on either side, so as to allow of its being heated with gas-burners; a thermometer inserted in the bath makes it possible to regulate the temperature as may be desired. This bath has two openings, closed with glass plates, corresponding to the two tubes carrying the lenses, and the crystal-section, held as usual in the pincers, is seen through these glass windows. Suitable accessories to the refractometer also allow of the measurement of the refractive indices at different temperatures.

In the case of *orthorhombic* crystals, the position of the three rectangular ether-axes cannot alter, since they must always coincide with the crystallographic axes. The values of the refractive indices, however, may change, and hence with them also the optic axial angle; indeed a change of axial plane or of the optical character is thus possible.

With *monoclinic* crystals, one ether-axis must coincide at all temperatures with the axis of symmetry, but the position of the other two in the plane of symmetry may alter, and this, with the possible change in the value of the refractive indices, may cause a variation in the degree (or kind) of dispersion as well as in the axial angle.

With *triclinic* crystals, both the positions of the ether-axes and the values of the refractive indices may change. The observed optical characters may therefore vary widely.

A striking example of the change of optical characters with change of temperature is furnished by gypsum, as investigated by Des Cloizeaux. At ordinary temperatures, the dispersion is inclined, the optic axial plane is $\parallel b(010)$ and $2E_r = 95°$. As the temperature rises this angle diminishes; thus, at 47°, $2E_r = 76°$; at 95°, $2E_r = 39°$; and at 116°, $2E_r = 0$. At this last temperature the axes for blue rays have already separated in a plane $\perp b(010)$; at 120° the axes for red rays also separate in this plane ($\perp b$) and the dispersion becomes *horizontal*. The motion toward the center of one red axis is more rapid than that of the other, namely, between 20° and 95°, one axis moves 33° 55′ while the other moves only 22° 38′; thus Bx_r moves 5° 38′.

Another interesting case is that of glauberite. Its optical characters under normal conditions are described as follows: Optically −. Ax. pl. $\perp b(010)$, $Bx_{a.r} \wedge c$ axis $= -31° 3'$, $Bx_{a.y} \wedge c$ axis $= -30° 46'$, $Bx_{a.bl} \wedge c$ axis $= -30° 10'$. The optical character (−) and the position of the axes of elasticity remain sensibly constant between 0° and 100°. The ax. pl., however, at first $\perp b(010)$ with horizontal dispersion and $\upsilon < \rho$ becomes on rise of temperature $\parallel b$ with inclined dispersion and $\upsilon > \rho$. The axial angle accordingly diminishes to 0° at a temperature depending upon the wave-length and then increases in the new plane. In white light, therefore, the interference-figures are abnormal and change with rise in temperature.

Des Cloizeaux found that the feldspars, when heated up to a certain point, suffer a change in the position of the axes, and if the heat becomes greater and is long continued they do not return again to their original position, but remain altered.

In addition to the typical cases referred to, it is to be noted that when elevation of temperature is connected with change of chemical composition wide changes in optical characters are possible. This is illustrated by the zeolites and related species, where the effect of loss of water has been particularly investigated.

Further, with some crystals, heat serves to bring about a change of molecular structure and with that a total change of optical characters. For example, the greenish-yellow (artificial) orthorhombic crystals of antimony iodide (SbI_3) on heating (to about 114°) change to red uniaxial hexagonal crystals. Note also the remarks made later in regard to the effect of heat upon leucite and boracite (Art. **429**).

423. Some Peculiarities in Axial Interference-figures.* — In the case of uniaxial crystals, the characteristic interference-figure varies but little from one species to another, such variation as is observed being usually due to the thickness of the section and the birefringence. In some cases, however, peculiarities are noted. For example, the interference-figure of apophyllite is somewhat peculiar, since its birefringence is very weak, and it may be optically positive for one part of the spectrum and negative for the other.

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* Variations in the axial figures embraced under the head of optical anomalies are spoken of later (Art. **429**).

In the case of biaxial crystals, peculiarities are more common. The following are some typical examples:

Brookite is optically + and the acute bisectrix is always normal to *a*(100). While, however, the axial plane is || *c*(001) for red and yellow, with $2E_r = 55°$, $2E_y = 30°$, it is commonly || *b*(010) for green and blue, with $2E_{gr} = 34°$. Hence a section || *a*(100) in the conoscope shows a figure somewhat resembling that of a uniaxial crystal but with four sets of hyperbolic bands.

Titanite also gives a peculiar interference-figure with colored hyperbolas because of the high color-dispersion, $\rho > \upsilon$, the variation between $2E$ for red and green light being approximately 10°; the dispersion of the bisectrices is, however, very small.

The most striking cases of peculiar axial figures are afforded by twin crystals (Art. **425**).

424. Relation of Optical Properties to Chemical Composition. — The effect of varying chemical composition upon the optical characters has been minutely studied in the case of many series of isomorphous salts, and with important results. It is, indeed, only a part of the general subject of the relation between crystalline form and molecular structure on the one hand and chemical composition on the other, one part of which has been discussed in Art. **322**. It was shown there that the refractive index can often be approximately calculated from the chemical composition.

Among minerals, the most important examples of the relation between composition and optical characters are afforded by the triclinic feldspars of the albite-anorthite series. Here, as explained in detail in the descriptive part of this work, the relation is so close that the composition of any intermediate member of this isomorphous group can be predicted from the position of its ether-axes, or more simply from the vibration directions on the fundamental cleavage-directions, || *c*(001) and || *b*(010).

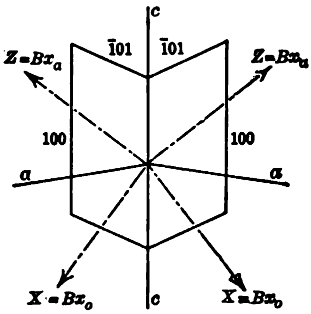
The effect of varying amounts of iron protoxide (FeO) is illustrated in the case of the monoclinic pyroxenes, where, for example, the angle $Bx_a \wedge c$ axis is 38° in diopside (2·9 p. c. FeO) and 47° in hedenbergite (26 p. c. FeO). This is also shown in the closely related orthorhombic species of the same group, enstatite, $MgSiO_3$ with little iron, and hypersthene, $(Mg,Fe)SiO_3$ with iron to nearly 30 p. c. With both of these species the axial plane is parallel to *b*(010), but the former is optically + ($Bx_a = Z$) and the dispersion $\rho < \upsilon$; the latter is optically − ($Bx_a = X$) and dispersion $\rho > \upsilon$. In other words,the optic axial angle changes rapidly with the FeO percentage, being about 90° for FeO = 10 p. c. In the case of the chrysolites, the epidotes, the species triphylite and lithiophilite, and others, analogous relations have been made out.

425. Optical Properties of Twin Crystals. — The examination of sections of twin crystals of any other than the isometric system in polarized light serves to establish the compound character at once and also to show the relative orientation of the several parts. This is most distinct in the case of contact-twins, but is also well shown with penetration-twins, though here the parts are usually not separated by a sharp line.

Thus the examination of a section parallel to *b*(010) of a twin crystal of gypsum, of the type of Fig. 608, makes it easy not only to establish the fact of the twinning but also to fix the relative positions of the ether-axes in the two parts. The measurement can in such cases be made between the extinction-directions in the two halves, instead of between one of these and some definite crystallographic line, as the vertical axis.

The polysynthetic twinning of certain species, as the triclinic feldspars, appears with great distinctness in polarized light. For example, in the case of a section of albite, parallel to the basal cleavage, the alternate bands extinguish together and assume the same tint when the quartz section is inserted. Hence the angle between these directions is easily measured, and this is obviously double the extinction-angle made with the edge *b*(010) ∧ *c*(001). A basal section of microcline in the same way shows its compound twinning according to both the albite and pericline laws, the characteristic grating structure being clearly revealed in polarized light. Fig. 609 of a section of chondrodite (from Des Cloizeaux) shows how the compound structure is shown by optical examination; the position of the axial plane is indicated in the case of the successive polysynthetic lamellæ. The complex penetration-twins of right- and left-handed crystals of quartz (see the description of that species), also have their character strikingly revealed in polarized light.

608



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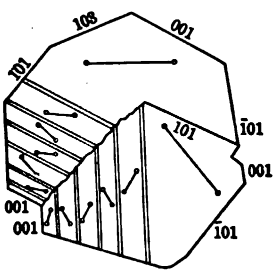

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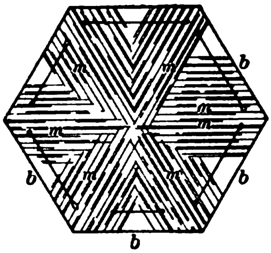
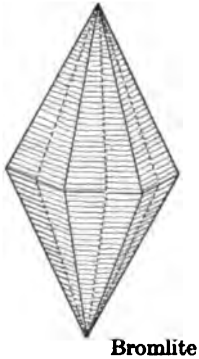


Witherite

611



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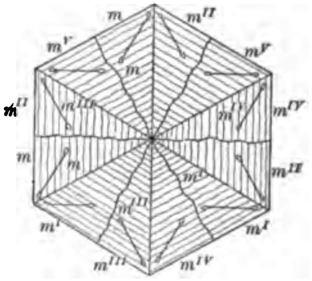
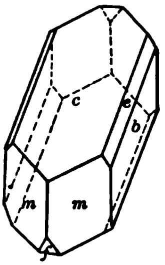


Bromlite (Des Cloizeaux)

Still again, the true structure of complex multiple twins, exhibiting pseudo-symmetry in their external form, can only be fully made out in this way. This is illustrated by Fig. 610, a basal section of an apparent hexagonal pyramid of witherite. The analogous six-sided pyramid of bromlite (Fig. 611) has a still more complex structure, as shown in Fig. 612. Fig. 613 shows a simple crystal of stilbite; Fig. 614 is the common type of twin-crystal, and Fig. 615 illustrates how the complex structure (||b010) is revealed in polarized

613



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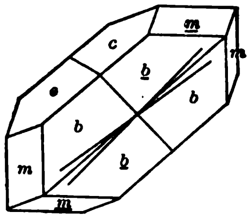

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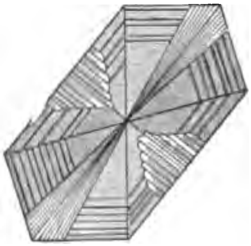

Stilbite (Lasaulx)

light. Other illustrations are given in Art. **429**. It will be understood that the axial interference-figures of twin crystals, where the parts are superposed, often show many peculiarities; the Airy spirals of quartz (p. 270) will serve as an illustration.

426. A particularly interesting case, related to the subject discussed in the preceding article, is that of the special properties of superposed cleavage-sections of mica. If three or more of these, say of rectangular form, be superposed and so placed that the lines of the axial planes make equal angles of 60° (45°, etc.) with each other the effect is that polarized light which has passed through the center suffers circular polarization, with a rotation to right or left according to the way in which the sections are built up. The interference-figure resembles that of a section of quartz cut normal to the axis.

If the sections are numerous and very thin the imitation of the phenomena of quartz is closer. These facts throw much light upon the ultimate molecular structure of a crystallized medium showing circular polarization. Further, it is easy from this to understand how it is possible to have in sections of certain crystals (*e.g.*, of clinochlore) portions which are biaxial and others that are uniaxial, the latter being due to an intimate twinning after this method of biaxial portions.

427. Optical Properties of Crystalline Aggregates. — The special optical phenomena of the different kinds of crystalline aggregates described on pp. 182, 183, and the extent to which their optical characters can be determined, depend upon the distinctness in the development of the individuals and their relative orientation. The case of ordinary granular, fibrous, or columnar aggregates needs no special discussion. Where, however, the doubly refracting grains are extremely small, the microscope may hardly serve to do more than to show the *aggregate polarization* present.

A case of special interest is that of spherulites, that is, aggregates spherical in form and radiated or concentric in structure; such aggregates occur with calcite, various chlorites, feldspars, etc. If they are formed of a doubly refracting crystalline mineral, or of an amorphous substance which has birefringent characters due to internal tension, they commonly exhibit a dark cross in the microscope between crossed nicols; further, this cross, as the section is revolved on the stage, though actually stationary, seems to rotate backward.

A distinct and more special case is that of spherical aggregates of a mineral optically uniaxial (or biaxial with a small angle). Sections of these (not central) in parallel polarized light show more or less distinctly the interference-figure of a uniaxial crystal. The objective must be focussed on a point a little removed from the section itself, say on the surface of the sphere of which it is a part. In such cases the + or − character of the double refraction can be determined as usual.

428. Change of Optical Character Induced by Pressure. — As the difference between the optical phenomena exhibited by an isometric crystal on the one hand and a uniaxial or biaxial crystal on the other is referred to a difference in molecular structure modifying the properties of the ether, it would be inferred that if an amorphous substance were subjected to conditions tending to develop an analogous difference in its molecular structure it would also show doubly refracting properties.

This is found to be the case. Glass which has been suddenly cooled from a state of fusion, and which is therefore characterized by strong internal tension, usually shows marked double refraction. Further, glass plates subjected to great mechanical pressure in one direction show in polarized light more or less distinct interference-curves. Gelatine sections, also, under pressure exhibit like phenomena. Even the strain in a glass block developed under the influence of unlike charges of electricity of great difference of potential on its opposite sides is sufficient to make it doubly refracting.

In an analogous manner the double refraction of a crystal may be changed by the application of mechanical force. Pressure exerted normal to the vertical axis of a section of a tetragonal or hexagonal crystal which has been cut ⊥ c axis, changes the uniaxial interference-figure into a biaxial, and with substances optically positive, the plane of the optic axes is parallel, and with negative substances normal, to the direction of pressure.

The quartz crystals in rocks, which have been subjected to great pressure, are often found to be in an abnormal state of tension, showing an undulatory extinction in polarized light.

429. Optical Anomalies. — Since the early investigations of Brewster, Herschel, and others (1815 *et seq.*) it has been recognized that many crystals exhibit optical phenomena which are not in harmony with the apparent symmetry of their external form. Crystals of many isometric species, as analcite, alum, boracite, garnet, etc., often show more or less pronounced double refraction, and sometimes they are distinctly uniaxial or biaxial. A section examined in parallel polarized light may show more or less sharply defined doubly refracting areas, or parallel bands or lamellæ with varying extinction. Occasionally, as noted by Klein in the case of garnet, while most crystals are normally isotropic, others show optical characters which seem to be determined by the external bounding faces and edges; thus, a dodecahedron may appear to be made up of twelve rhombic pyramids (biaxial) whose apices are at the center; a hexoctahedron similarly may seem to be made up of forty-eight triangular pyramids, etc.

Similarly, crystals of many common tetragonal or hexagonal species, as vesuvianite, zircon, beryl, apatite, corundum, chabazite, etc., give interference-figures resembling those of biaxial crystals. Also, analogous contradictions between form and optical characters are noted with crystals of orthorhombic and monoclinic species, *e.g.*, topaz, natrolite, orthoclase, etc. All cases such as those mentioned are embraced under the common term of *optical anomalies.*

This subject has been minutely studied by many investigators in recent years and important additions have been made to it both on the practical and the theoretical side. The result is that, though doubtful cases still remain, many of the typical ones have found a satisfactory explanation. No single theory, however, can be universally applied.

The chief question involved has been whether the anomalies are to be considered as secondary and non-essential, or whether they belong to the inherent molecular structure of the crystals in question. On the one hand, it has been urged that internal tension suffices (Art. **428**) to call out double refraction in an isotropic substance or to give a uniaxial crystal the typical optical structure of a biaxial crystal. On the other hand, it is equally clear that twinning often produces pseudo-symmetry in external form, and at the same time conceals or changes the optical characters. From the simplest case, as that of aragonite, we pass to more complex cases, as witherite (Fig. 610), bromlite (Figs. 611, 612), phillipsite (Figs. 400, 452–454), which last is sometimes pseudo-isometric in form though optical study shows the monoclinic character of the individuals.* Reasoning from the analogy of these last cases, Mallard was led (1876) to the theory that the optical anomalies could in most cases be explained by the assumption of a similar but still more intimate grouping of molecules which themselves without this would unite to form crystals of a lower grade of symmetry than that which their complex twinned crystals actually simulate.

In regard to the two points of view mentioned, it seems probable that internal tension (due to pressure, sudden cooling, or rapidity of growth, etc.) can be safely appealed to to explain the anomalous optical character of many species, as diamond, halite, beryl, quartz, etc. Again, it has been fully proved that the later growth of isomorphous layers of varying composition may produce optical anomalies, probably here also to be referred to tension. Alum is a striking example. The peculiarities of this species were early investigated by Biot and made by him the basis of his theory of "lamellar polarization," but the present explanation is doubtless the true one. Fig. 616 (from Brauns) shows the appearance in polarized light of a section || *o*(111) from a crystal in which the successive layers have different composition. Further, according to Brauns, the optical peculiarities of many other species may be referred to this same cause. He includes here, particularly, those cases (as with some garnets) in which the optical characters seem to depend upon the external form, as noted above. Here belongs also apophyllite, a section of which (from Golden, Col., by Klein) is shown in Fig. 617. The section has been cut || *c*(001) through the center of the crystal and is represented as it appears in parallel polarized light.

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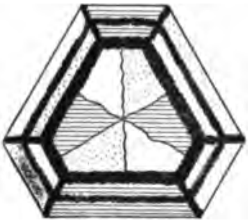
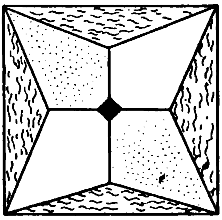
* Crystals showing pseudo-symmetry of highly complex type are called *mimetic* crystals by Tschermak.

616



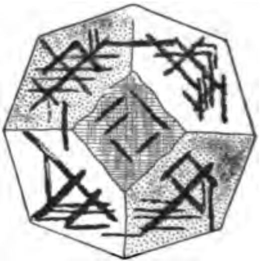
Alum, || 111

617



Apophyllite, || 001

618



Leucite, || 100

Another quite distinct but most important class is that including species such as boracite and leucite, which are *dimorphous;* that is, those species which at a certain elevation of temperature (300° for boracite and 500° to 600° for leucite) become strictly isotropic. Under ordinary conditions, these species are anisotropic, but the fact stated makes it probable that originally their crystalline form and optical characters were in harmony. The relations for leucite deserve to be more minutely stated.

Leucite usually shows very feeble double refraction: $\omega = 1{\cdot}508$, $\epsilon = 1{\cdot}509$. This anomalous double refraction, early noted (Brewster, Biot), was variously explained. In 1873, Rath, on the basis of careful measurements, referred the seemingly isometric crystals to the tetragonal system, the trapezohedral face 112 being taken as 111 and 211, 121 as 421, 241, respectively; also 101, 011 as 201, 021. Later Weisbach (1880), on the same ground, made them orthorhombic; Mallard, however, referred them (1876), chiefly on optical grounds, to the monoclinic system, and Fouqué and Lévy (1879) to the triclinic. The true symmetry, corresponding to the molecular structure which they possess or tend to possess at ordinary temperatures, is in doubt, but it has been shown (Klein, Penfield) that at 500° to 600° sections become isotropic; and further (Rosenbusch) that the twinning striations disappear on heating, to reappear again in new position on cooling. Sections ordinarily show twinning-lamellæ || *d*(110); in some cases a bisectrix (+) is normal to what corresponds to a cubic face, the axial angle being very small. The structure corresponds in general (Klein) to the interpenetration of three crystals, in twinning position || *d*, which may be equally or unequally developed; or there may be one fundamental individual with inclosed twinning-lamellæ. Fig. 618 shows a section of a crystal (|| *a*, 100) which is apparently made up by the twinning of three individuals.

Still again, in a limited number of cases, it can be shown that the intergrowth of lamellæ having slightly different crystallographic orientation is the cause of the optical peculiarities. Prehnite is a conspicuous example of this class.

After all the various possible explanations have been applied there still remain, however, many species about which no certain conclusion can be reached. To many of these species the theory of Mallard may probably be applicable. Indeed it may be added that much difference of opinion still exists as to the cause of the "optical anomalies" in a considerable number of minerals.

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IV. CHARACTERS DEPENDING UPON HEAT

430. The more important of the special properties of a mineral species with respect to heat include the following: Fusibility; conductivity and expansion, especially in their relation to crystalline structure; change in optical characters with change of temperature; specific heat; also diathermancy, or the power of transmitting heat radiation. The full discussion of these and other related subjects lies outside of the range of the present text-book. A few brief remarks are made upon them, and beyond these reference must be made to text-books on Physics and to special memoirs, some of which are mentioned in the literature (p. 305).

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* A complete bibliography is given in the memoir by Brauns (1891), see above.

431. Fusibility. — The approximate relative fusibility of different minerals is an important character in distinguishing different species from one another by means of the blowpipe. For this purpose a scale is conveniently used for comparison, as explained in the articles later devoted to the blowpipe. Accurate determinations of the fusibility are difficult, and though of little importance for the above object, they are interesting from a theoretical standpoint. They have been attempted by various authors by the use of a number of different methods. The following are the approximate melting-point values for the minerals used in von Kobell's scale (Art. **491**): Stibnite, 525°; natrolite, 965°; almandite, 1200°; actinolite, 1296°; orthoclase, 1200°; bronzite, 1380°; also for quartz, about 1600°.

432. Conductivity. — The conducting power of different crystallized media was early investigated by Sénarmont. He covered the faces of the substance under investigation with wax and observed the form of the figure melted by a hot wire placed in contact with the surface at its middle point. Later investigations have been made by Röntgen (who modified the method of Sénarmont), by Jannettaz, and others. In general it is found that, as regards their thermal conductivity, crystals are to be divided into the three classes noted on p. 252. In other words, the conductivity for heat seems to follow the same general laws as the propagation of light. It is to be stated, however, that experiments by S. P. Thompson and O. J. Lodge have shown a different rate of conductivity in tourmaline in the opposite directions of the vertical axis.

433. Expansion. — Expansion, that is, increase in volume upon rise of temperature, is a nearly universal property for all solids. The increment of volume for the unit volume in passing from 0° to 1° C. is called the coefficient of expansion. This quantity has been determined for a number of species. Further, the relative expansion in different directions is found to obey the same laws as the light-propagation. Crystals, as regards heat-expansion, are thus divided into the same three classes mentioned on p. 252 and referred to in the preceding article.

The amount of expansion varies widely, and, as shown by Jannettaz, is influenced particularly by the cleavage. Mitscherlich found that in calcite there was a diminution of 8′ 37″ in the angle of the rhombohedron on passing from 0° to 100° C., the form thus approaching that of a cube as the temperature increased. The rhombohedron of dolomite, for the same range of temperature, diminishes 4′ 46″; and in aragonite, for a rise in temperature from 21° to 100°, the angle of the prism diminishes 2′ 46″. In some rhombohedrons, as of calcite, the vertical axis is lengthened (and the horizontal shortened), while in others, like quartz, the reverse is true. The variation is such in both cases that the birefringence is diminished with the increase of temperature, for calcite possesses negative double refraction, and quartz, positive.

It is to be noted that in general the expansion by heat, while it may serve to alter the angles of crystals, other than those of the isometric system, does not alter the zone-relations and the crystalline symmetry. In certain cases, however, the effect of heat may be to give rise to twinning-lamellæ (as in anhydrite) or to cause their disappearance (as in calcite). Rarely heat serves to develop a new molecular structure; thus, as explained in Art. **429**, boracite and leucite, which are anisotropic at ordinary temperatures, become isotropic when heated, the former to 300° the latter to 500° or 600°. The change in the optical properties of crystals produced by heat has already been noticed (Art. **422**).

434. Specific Heat. — Determinations of the specific heat of many minerals have been made by Joly, by Oeberg, and others. Some of the results reached are as follows:

	Joly	Oeberg		Joly	Oeberg
Galena, *cryst.*	0·0541	—	Orthoclase	0·1869	0·1877
Chalcopyrite	0·1271	0·1291	Albite	0·1983	0·1976
Pyrite	0·1306	—	Amphibole, *black*	0·1963	Augite 0·1830
Hematite	0·1683	0·1645	Beryl	0·2066	0·1979
Garnet, *red cryst.*	0·1780 – 0·1793	0·1758	Calcite	0·2034 – 0·2044	0·2042
Epidote	0·1877	0·1861	Aragonite	0·2036	—

435. Diathermancy. — Besides the slow molecular propagation of heat in a body, measured by its thermal conductivity, there is also to be considered the rapid propagation of what is called radiant heat through it by the wave-motion of the ether which surrounds its molecules. This is merely a part of the general subject of light-propagation already fully discussed, since heat-waves, in the restricted sense, differ from light-waves only in their relatively greater length. The degree of absorption exerted by the body is measured by its diathermancy, which corresponds to transparency in light. In this sense halite, sylvite, and fluorite are highly *diathermanous*, since they absorb but little of the heat-waves passing through them; on the other hand, gypsum and, still more, alum are comparatively *athermanous*, since while transparent to the short light-waves they absorb the long heat-waves, transforming the energy into that of sensible heat. Measurements of the diathermancy were early made by Melloni, later by Tyndall, Langley, and others.

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V. CHARACTERS DEPENDING UPON ELECTRICITY AND MAGNETISM

1. ELECTRICITY

436. Electrical Conductivity. — The subject of the relative conducting power of different minerals is one of minor interest.* In general most minerals, except those having a metallic luster among the sulphides and oxides, are non-conductors. Only the non-conductors can show pyro-electrical phenomena, and only the conductors can give a thermo-electric current.

437. Frictional Electricity. — The development of an electrical charge on many bodies *by friction* is a familiar subject. All minerals become electric by friction, although the degree to which this is manifested differs widely. There is no line of distinction among minerals, dividing them into *positively* electric and *negatively* electric; for both electrical states may be presented by different varieties of the same species, and by the same variety in different states. The gems are in general positively electric only when polished; the diamond, however, exhibits positive electricity whether polished or not. It is a familiar fact that the electrification of amber upon friction was early observed (600 B. C.), and indeed the Greek name (ἤλεκτρον) later gave rise to the word electricity.

438. Pyro-electricity. — The simultaneous development of positive and negative charges of electricity on different parts of the same crystal when its temperature is suitably changed is called pyro-electricity. Crystals exhibiting such phenomena are said to be *pyro-electric.* This phenomenon was first observed in the case of tourmaline, which is rhombohedral-hemimorphic in crystallization, and it is particularly marked with crystals belonging to groups of relatively low symmetry, especially those of the hemimorphic type. It is possible, of course, only with non-conductors. This subject was early investigated by Riess and Rose (1843), later by Hankel, also by C. Friedel, Kundt, and others (see literature).

In all cases it is true that directions of like crystallographic symmetry show charges of like sign, while unlike directions may exhibit opposite charges. Substances not crystallized cannot show pyro-electricity. A few of the many possible examples will serve to bring out the most essential points.

Boracite (isometric-tetrahedral, p. 66) on heating exhibits + electricity on one set of tetrahedral faces and − electricity on the other. Cf. Fig. 619.

Tourmaline (rhombohedral-hemimorphic, p. 109) shows opposite charges at the opposite extremities of the vertical axis corresponding to its hemimorphic crystallization. In this and in other similar cases, the extremity which becomes positive on heating has been called the *analogous* pole, and that which becomes negative has been called the *antilogous* pole.

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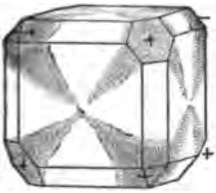
* On the conductivity of minerals, see Beijerinck, Jb. Min., Beil.-Bd., **11**, 403, 1898.

Calamine and *struvite* (orthorhombic-hemimorphic, p. 126) exhibit phenomena analogous to those of tourmaline.

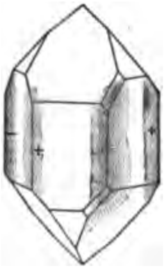
Quartz (rhombohedral-trapezohedral, p. 112) shows + electricity on heating at the three alternate prismatic edges and − electricity at the three remaining edges; the distribution for right-handed crystals is opposite to that of left-handed. Twins may exhibit a high degree of complexity. Cf. Figs. 620, 621.

Axinite (triclinic, p. 144), when heated to 120° or 130°, has an analogous pole (Riess & Rose) at the solid angle rxM'; the antilogous pole at the angle $mr'M'$ near plane n.

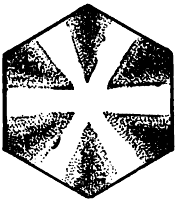
619



620



621



A very convenient and simple method for investigating the phenomena is the following, which is due to Kundt: First heat the crystal or section carefully in an air-bath; pass it several times through the flame of an alcohol lamp and then place it on a little upright cylinder of brass to cool. While cooling, a mixture of red lead and sulphur finely pulverized and previously agitated is dusted over it through a fine cloth from a suitable bellows. The positively electrified red lead collects on the parts having a negative charge, and the negatively electrified sulphur on those with a positive charge. This is illustrated by Figs. 619–621, and still better by the illustrations given by Kundt and others. (Cf. Plate III of Groth, Phys. Kryst., 1905.)

439. Piezo-electricity. — The name *piezo-electricity* has been given to the development of electrical charges on a crystallized body by pressure. This is shown by a cleavage mass of calcite, also by topaz. This phenomenon is most interesting where a relation can be established between the electrical excitement and the molecular structure, as is conspicuously true with quartz, tourmaline, and some other species.

This subject has been investigated by Hankel, Curie, and others, and discussed theoretically by Lord Kelvin (see literature). Hankel has also employed the term *actino-electricity*, or, better, *photo-electricity*, for the phenomenon of producing an electrical condition by the influence of direct radiation; fluorite is a conspicuous example.

440. Thermo-electricity. — The contact of two unlike metals in general results in electrifying one of them positively and the other negatively. If, further, the point of contact be heated while the other parts, connected with a wire, are kept cool, a continuous current of electricity — shown, for example, by a suitable galvanometer — is set up at the expense of the heat-energy supplied. If, on the other hand, the point of junction is cooled, a current is set up in the reverse direction. This phenomenon is called *thermo-electricity*, and two metals so connected constitute a thermo-electric couple. Further it is found that different conductors can be arranged in order in a table — a so-called thermo-electric series — according to the *direction* of the current set up on heating and according to the *electromotive force* of this current. Among the metals, bismuth (+) and antimony (−) stand at the opposite ends of the series; the current passes through the connecting wire from antimony to bismuth.

This subject is so far important for mineralogy, as it was shown by Bunsen that the natural metallic sulphides stand farther off in the series than bismuth and antimony, and consequently by them a higher electromotive force is produced. The thermo-electrical relations of a large number of minerals were determined by Flight.

It was early observed that some minerals have varieties which are both + and −. Rose attempted to establish a relation between the positive and negative pyritohedral forms of pyrite and cobaltite, and the positive or negative thermo-electrical character. Later investigations by Schrauf and Dana have shown, however, that the same peculiarity belongs also to glaucodot, tetradymite, skutterudite, danaite, and other minerals, and it is demonstrated by them that it cannot be dependent upon crystalline form, but rather upon chemical composition.

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2. MAGNETISM

441. Magnetic Minerals. Natural Magnets. — A few minerals in their natural state are capable of being attracted by a strong steel magnet; they are said to be *magnetic*. This is conspicuously true of magnetite, the magnetic oxide of iron; also of pyrrhotite or magnetic pyrites, and of some varieties of native platinum (especially the variety called iron-platinum).

A number of other minerals, as hematite, franklinite, etc., are in some cases attracted by a steel magnet, but probably in most if not all cases because of admixed magnetite (but see Art. **443**). Occasional varieties of the three minerals mentioned above, as the lodestone variety of magnetite, exhibit themselves the attracting power and polarity of a true magnet. They are then called *natural magnets*. In such cases the magnetic polarity has probably been derived from the inductive action of the earth, which is itself a huge magnet.

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* See Liebisch, Phys. Krystallographie, 1891, for a full discussion of the topics briefly touched upon in the preceding pages, also for references to original articles.

442. Paramagnetism. Diamagnetism. — In a very strong magnetic field, as that between the poles of a very powerful electromagnet, all minerals, as indeed all other substances, are influenced by the magnetic force. According to their behavior they are divided into two classes, the *paramagnetic* and *diamagnetic;* those of the former appear to be attracted, those of the latter to be repelled. For purposes of experiment the substance in question, in the form of a rod, is suspended on a horizontal axis between the poles of the magnet. If paramagnetic, it takes a position parallel to the magnetic axis; if diamagnetic, it sets transversely to it. Iron, cobalt, nickel, manganese, platinum are paramagnetic; silver, copper, bismuth are diamagnetic. Among minerals compounds of iron are paramagnetic, as siderite, also diopside; further, beryl, dioptase. Diamagnetic species include calcite, zircon, wulfenite, etc.

By the use of a sphere it is possible to determine the relative amount of magnetic induction in different directions of the same substance. Experiment has shown that in isometric crystals the magnetic induction is alike in all directions; that in those optically uniaxial, there is a direction of maximum and, normal to it, one of minimum magnetic induction; that in biaxial crystals, there are three unequal magnetic axes, the position of which may be determined. In other words, the magnetic relations of the three classes of crystals are analogous to their optical relations.

443. Corresponding to the facts just stated, that all compounds of iron are paramagnetic, it is found that a sufficiently powerful electromagnet attracts all minerals containing iron, though, except in the cases given in Art. **441**, a bar magnet has no sensible influence upon them; hence the efficiency of the electromagnetic method of separating ores.

Plücker [*] determined the magnetic attraction of a number of substances compared with iron taken as 100,000. For example, for magnetite he obtained 40,227; for hematite, crystallized, 533, massive, 134; limonite, 71; pyrite, 150.

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[*] Pogg. Ann., **74**, 343, 1848.

VI. TASTE AND ODOR

In their action upon the senses a few minerals possess *taste*, and others under some circumstances give off *odor*.

444. Taste belongs only to soluble minerals. The different kinds of taste adopted for reference are as follows:

1. *Astringent:* the taste of vitriol.
2. *Sweetish astringent:* taste of alum.
3. *Saline:* taste of common salt.
4. *Alkaline:* taste of soda.
5. *Cooling:* taste of saltpeter.
6. *Bitter:* taste of Epsom salts.
7. *Sour:* taste of sulphuric acid.

445. Odor. — Excepting a few gaseous and soluble species, minerals in the dry unchanged state do not give off odor. By friction, moistening with the breath, and the elimination of some volatile ingredient by heat or acids, odors are sometimes obtained which are thus designated:

1. *Alliaceous:* the odor of garlic. Friction of arsenopyrite elicits this odor; it may also be obtained from arsenical compounds by means of heat.

2. *Horse-radish odor:* the odor of decaying horse-radish. This odor is strongly perceived when the ores of selenium are heated.

3. *Sulphurous:* friction elicits this odor from pyrite, and heat from many sulphides.

4. *Bituminous:* the odor of bitumen.

5. *Fetid:* the odor of sulphureted hydrogen or rotten eggs. It is elicited by friction from some varieties of quartz and limestone.

6. *Argillaceous:* the odor of moistened clay. It is obtained from serpentine and some allied minerals, after moistening them with the breath; others, as pyrargillite, afford it when heated.

446. Feel. — The FEEL is a character which is occasionally of some importance; it is said to be *smooth* (sepiolite), *greasy* (talc), *harsh*, or *meager*, etc. Some minerals, in consequence of their hygroscopic character, *adhere to the tongue* when brought in contact with it.

PART III. CHEMICAL MINERALOGY

GENERAL PRINCIPLES OF CHEMISTRY AS APPLIED TO MINERALS

447. Minerals, as regards their chemical constitution, are either the uncombined elements in a native state, or definite compounds of these elements formed in accordance with chemical laws. It is the object of Chemical Mineralogy to determine the chemical composition of each species; to show the chemical relations of different species to each other where such exist; and also to explain the methods of distinguishing different minerals by chemical means. It thus embraces the most important part of Determinative Mineralogy.

In order to understand the chemical constitution of minerals, some knowledge of the fundamental principles of Chemical Philosophy is required; and these are here briefly recapitulated.

448. Chemical Elements. — Chemistry recognizes about eighty substances which cannot at will be decomposed, or divided into others, by any process of analysis at present known; these substances are called the chemical *elements*. A list of them is given in a later article (**452**); common examples are: Oxygen, nitrogen, hydrogen, chlorine, gold, silver, sodium, etc.

449. Atom. Molecule. — The study of the chemical properties of substances and of the laws governing their formation has led to the belief that there is for each element a definite, indivisible mass, which is the smallest particle which can play a part in chemical reactions; this indivisible unit is called the *atom*.

With some rare exceptions, the atom cannot exist alone, but unites by the action of what is called chemical force, or chemical affinity, with other atoms of the same or different kind to form the *molecule*. The molecule, in the chemical sense, may be defined as the smallest particle into which a given kind of substance can be subdivided without undergoing chemical decomposition. For example, two *atoms* of hydrogen unite to form a *molecule* of hydrogen gas. Again, one atom of hydrogen and one of chlorine form a molecule of hydrochloric acid gas; two atoms of hydrogen and one of sulphur form a molecule of the gas hydrogen sulphide.

450. Atomic Weight. — The atomic weight of an element is the weight, or, better expressed, the mass of its atom compared with that of the element hydrogen taken as the unit or with the weight of an atom of oxygen taken as 16. Of the methods by which the relation between the masses of the atoms is determined it is unnecessary here to speak; the results that have been obtained are given in the table on p. 312.

451. Symbol. Formula. — The symbol of an element is the initial letter, or letters, often of its Latin name, by which it is represented when expressing in chemical notation the constitution of substances into the composition of which it enters. Thus O is the symbol of oxygen, H of hydrogen, Cl of chlorine, Fe (from *ferrum*) of iron, Ag (from *argentum*) of silver, etc. Further, this symbol is always understood to indicate that definite amount of the given element expressed by its atomic weight; in other words, it represents one atom. If twice this quantity is involved, that is, two atoms, this is indicated by a small subscript number written immediately after the symbol. Thus, Sb_2S_3 means a compound consisting of two atoms of antimony and three of sulphur, or of 2 × 120 parts by weight of antimony and 3 × 32 of sulphur.

This expression, Sb_2S_3, is called the *formula* of the given compound, since it expresses in briefest form its composition. Similarly the formula of the mineral albite is $NaAlSi_3O_8$.

Strictly speaking, such formulas are merely *empirical formulas*, since they express only the actual result of analysis, as giving the relative number of atoms of each element present, and make no attempt to represent the actual constitution. A formula developed with the latter object in view is called a rational, structural, or constitutional formula (see Art. **469**).

452. Table of the Elements. — The following table gives a list of all the definitely established elements with their accepted symbols and also their atomic weights.*

Of the elements given in this list — more than eighty in all — only a very small number, say twelve, play an important part in making up the crust of the earth and the water and air surrounding it. The common elements concerned in the composition of minerals are: Oxygen, sulphur, silicon, aluminium, iron, calcium, magnesium, sodium, potassium. Besides these, hydrogen is present in water, nitrogen in the air, and carbon in all animal and vegetable substances. Only a very few of the elements occur as such in nature, as native gold, native silver, native sulphur, etc.

Of the elements, oxygen, hydrogen, nitrogen, chlorine, and fluorine are gases; bromine is a volatile liquid; mercury is also a liquid, but the others are solids under ordinary conditions.

	Symbol	O = 16 At. Weight
Aluminium, Aluminum	Al	27·1
Antimony (*Stibium*)	Sb	120·2
Argon	A	39·9
Arsenic	As	74·9
Barium	Ba	137·4
Beryllium, Glucinum	Be (or Gl)	9·1
Bismuth	Bi	208·0
Boron	B	11·0
Bromine	Br	79·9
Cadmium	Cd	112·4
Cæsium	Cs	132·8
Calcium	Ca	40·1
Carbon	C	12·0
Cerium	Ce	140·2
Chlorine	Cl	35·5
Chromium	Cr	52·0
Cobalt	Co	59·0
Columbium, see *Niobium*		
Copper (*Cuprum*)	Cu	63·6
Dysprosium	Dy	162·5
Erbium	Er	167·7
Europium	Eu	152·0
Fluorine	F	19·0
Gadolinium	Gd	157·3
Gallium	Ga	69·9
Germanium	Ge	72·5
Glucinum, see *Beryllium*		
Gold (*Aurum*)	Au	197·2
Helium	He	4·0
Holmium	Ho	163·5
Hydrogen	H	1·0
Indium	In	114·8
Iodine	I	126·9
Iridium	Ir	193·1

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* These correspond in value to those commonly accepted, and are given accurate to one decimal place.

	Symbol	0=16 At. Weight
Iron (*Ferrum*)	Fe	55·8
Krypton	Kr	82·9
Lanthanum	La	139·0
Lead (*Plumbum*)	Pb	207·2
Lithium	Li	6·9
Lutecium	Lu	175·0
Magnesium	Mg	24·3
Manganese	Mn	54·9
Mercury (*Hydrargyrum*)	Hg	200·6
Molybdenum	Mo	96·0
Neodymium	Nd	144·3
Neon	Ne	20·2
Nickel	Ni	58·7
Niobium	Nb	93·1
Niton	Nt	222·4
Nitrogen	N	14·0
Osmium	Os	190·9
Oxygen	O	16·0
Palladium	Pd	106·7
Phosphorus	P	31·0
Platinum	Pt	195·2
Potassium (*Kalium*)	K	39·1
Praseodymium	Pr	140·9
Radium	Ra	226·0
Rhodium	Rh	102·9
Rubidium	Rb	85·5
Ruthenium	Ru	101·7
Samarium	Sa	150·4
Scandium	Sc	44·1
Selenium	Se	79·2
Silicon	Si	28·3
Silver (*Argentum*)	Ag	107·9
Sodium (*Natrium*)	Na	23·0
Strontium	Sr	87·6
Sulphur	S	32·0
Tantalum	Ta	181·5
Tellurium	Te	127·5
Terbium	Tb	159·2
Thallium	Tl	204·0
Thorium	Th	232·4
Thulium	Tm	168·5
Tin (*Stannum*)	Sn	118·7
Titanium	Ti	48·1
Tungsten (*Wolframium*)	W	184·0
Uranium	U	238·2
Vanadium	V	51·0
Xenon	Xe	130·2
Ytterbium	Yb	173·5
Yttrium	Yt	88·7
Zinc	Zn	65·4
Zirconium	Zr	90·6

453. Metals and Non-metals. — The elements may be divided into two more or less distinct classes, the metals and the non-metals. Between the two lie a number of elements sometimes called the semi-metals. The *metals*, as gold, silver, iron, sodium, are those elements which, *physically* described, possess to a more or less perfect degree the fundamental characters of the ideal metal, viz.: malleability, metallic luster (and opacity to light), conductivity for heat and electricity; moreover, *chemically* described, they commonly play the part of the positive or basic element in a simple compound, as later defined (Arts. **462–465**). The *non-metals*, as sulphur, carbon, silicon, etc., also the gases, as oxygen, chlorine, etc., have none of the physical characters alluded to: they are, if solids, brittle, often transparent to light-radiation, are poor conductors for heat and electricity. Chemically expressed, they usually play the negative or acid part in a simple compound.

The so-called *semi-metals*, or metalloids, include certain elements, as tellurium, arsenic, antimony, bismuth, which have the physical characters of a metal to a less perfect degree (*e.g.*, they are more or less brittle); and, more important than this, they often play the part of the acidic element in the compound into which they enter. These points are illustrated later.

It is to be understood that the distinctions between the classes of the elements named cannot be very sharply applied. Thus the typical metallic characters mentioned are possessed to a very unequal degree by the different substances classed as metals; for example, by silver and tin. Corresponding to this a number of the true metals, as tin and manganese, play the part of an acid in numerous salts. Further, the mineral magnetite, $\overset{II}{Fe}\overset{III}{Fe_2}O_4$, is often described as an *iron ferrate;* so that in this compound the same element would play the part of both acid and base.

454. Positive and Negative Elements. — It is common to make a distinction between the *electro-positive* and *electro-negative* element in a compound.

The passage of a sufficiently strong electrical current through a chemical compound in many cases results in its decomposition (or electrolysis) into its elements or parts. In such cases it is found that for each compound the atoms of one element collect at the negative pole (the cathode) and those of the other at the positive pole (the anode). The former is called the electro-positive element and the latter the electro-negative element. Thus in the electrolysis of water (H_2O) the hydrogen collects at the cathode and is hence called positive, and the oxygen at the anode and is called negative. Similarly, in hydrochloric acid (HCl) the hydrogen is thus shown to be positive, the chlorine negative. This distinction is also carried to complex compounds, as copper sulphate ($CuSO_4$), which by electrolysis is broken into Cu, which is found to be electro-positive, and SO_4 (the last separates into SO_3, forming H_2SO_4 and free oxygen).

For reasons which will be explained later, the positive element is said to play the basic part, the negative the acidic. The metals, as already stated, in most cases belong to the former class, the non-metals to the latter, while the semi-metals may play both parts.

It is common in writing the formula to put the positive or basic element first, thus H_2O, H_2S, HCl, H_2SO_4, Sb_2S_3, As_2O_3, AsH_3, $NiSb$, $FeAs_2$. Here it will be noted that antimony (Sb) and arsenic (As) are positive in some of the compounds named but negative in the others.

455. Periodic Law. — In order to understand the relations of the chief classes of chemical compounds represented among minerals, as still more their further subdivision, down finally to the many *isomorphous groups* — groups of species having analogous composition and closely similar form, as explained in Art. **471** — the fundamental relations and grouping of the elements must be understood, especially as developed of recent years and shown in the so-called Periodic Law.

Although the subject can be only briefly touched upon, it will be useful to give here the general distribution of the elements into Groups and Series, as presented in the Principles of Chemistry (Engl. Ed., 1891) of D. Mendeléeff, to whom is due more than any one else the development of the Periodic Law. When the elements are arranged according to the values of their atomic weights it is seen that they fall more or less into groups consisting of eight elements each, or double groups containing sixteen elements. The corresponding members of each group show similar chemical characters. The table given below will illustrate these relationships. For the thorough explanation of this subject, more particularly as regards the periodic or progressive relation between the atomic weights and various properties of the elements, the reader is referred to the work above mentioned or to one of the many other excellent modern text-books of chemistry.

The relations of some of the elements of the first group are exhibited by the isomorphism (see Art. **471**, also the description of the various groups and species here referred to, which are given in Part IV of this work) of $NaCl$, KCl, $AgCl$; or again of $LiMnPO_4$ and $NaMnPO_4$, etc. In the second group, reference may be made to the isomorphism of the carbonates and sulphates (p. 322) of calcium, barium, and strontium; while among the sulphides, ZnS, CaS, and HgS are doubly related. In the third group, we find boron and aluminium often replacing one another among silicates. In the fourth group, the relations of silicon and titanium are shown in the titano-silicates, while the compounds TiO_2, SnO_2, PbO_2 (and MnO_2), also $ZrSiO_4$ and $ThSiO_4$, have

TABLE OF PERIODIC SYSTEM

I	II	III	IV	V	VI	VII	VIII
Li=7	Be=9	B=11	C=12	N=14	O=16	F=19	
Na=23	Mg=24	Al=27	Si=22	P=31	S=32	Cl=35	
K=39	Ca=40	Sc=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56 Co=59 Ni=59
Cu=64	Zn=65	Ga=70	Ge=73	As=75	Se=79	Br=80	
Rb=85	Sr=88	Yt=89	Zr=91	Nb=93	Mo=96		Ru=102 Rh=103 Pd=107
Ag=108	Cd=112	In=115	Sn=119	Sb=120	Te=127	I=127	
Cs=133	Ba=137	La=139	Ce, etc. 140–175	Ta=181	W=184		Os=191 Ir=193 Pt=195
Au=197	Hg=201	Tl=204	Pb=207	Bi=208			
	Ra=226		Th=232		U=238		

closely similar form. In the fifth group, many compounds of arsenic, antimony, and bismuth are isomorphous among metallic compounds, while the relations of phosphorous, vanadium, arsenic, also antimony, are shown among the phosphates, vanadates, arsenates, and antimonates; again the mutual relations of the niobates and tantalates are to be noted.

In the sixth group, the strongly acidic elements, sulphur, selenium, tellurium, are all closely related, as seen in many sulphides, selenides, tellurides; further, the relations of sulphur and chromium, and similarly of both of these to molybdenum and tungsten, are shown among many artificial sulphates, chromates, molybdates, and tungstates.

In the seventh group the relations of the halogens are too well understood to need special remark. In the eighth group, we have Fe, Co, Ni alloyed in meteoric iron, and their phosphates and sulphates are in several cases closely isomorphous; further, the relation of the iron series to that of the platinum series is exhibited in the isomorphism of FeS_2, FeAsS, $FeAs_2$, etc., with $PtAs_2$ and probably RuS_2.

456. Combining Weight. — Chemical investigation proves that the mass of a given element entering into a compound is always proportional either to its atomic weight or to some simple multiple of this; the atomic weight is hence also called the *combining weight*. Thus in rock salt, sodium chloride, the masses involved of sodium and chlorine present are found by analysis to be equal to 39·4 and 60·6 in 100 parts, and these numbers are in proportion to 23 : 35·4, the atomic weights of sodium and chlorine; hence it is concluded that one atom of each is present in the compound. The formula is, therefore, NaCl. In calcium chloride, by the same method the masses present are found to be proportional to 39·9 : 70·8, that is, to 39·9 : 2 × 35·4; hence the formula is $CaCl_2$.

Still again, a series of compounds of nitrogen with oxygen is known in which the ratios of the masses of the two elements are as follows: (1) 28 : 16, (2) 14 : 16, (3) 28 : 48, (4) 14 : 32, (5) 28 : 80. It is seen at once that these must have the formulas (1) N_2O, (2) NO, (3) N_2O_3, (4) NO_2, (5) N_2O_5. On the contrary, atmospheric air which contains these elements in about the ratio of 76·8 to 23·2 cannot be a chemical compound of these elements, since (aside from other considerations) these numbers are not in the ratio of $n \times 14 : m \times 16$ where n and m are simple whole numbers.

457. Molecular Weight. — The molecular weight is the weight of the molecule of the given substance, expressed in terms of the mass of the hydrogen atom as unit. The molecular weight of hydrogen is 2 because the molecule can be shown to consist of two atoms. The molecular weight of hydrochloric acid (HCl) is 36·4, of water vapor (H_2O)' 18, of hydrogen sulphide (H_2S) 34.

Since, according to the law of Avagadro, like volumes of different gases under like conditions as to temperature and pressure contain the same number of molecules, it is obvious that the molecular weight of substances in the form of gas can be derived directly from the relative density or specific gravity. If the density is referred to hydrogen, whose molecular weight is 2, it will be always true that the molecular weight is twice the density in the state of a gas and *vice versa*. Thus the observed density of carbon dioxide (CO_2) is 22, hence its molecular weight must be 44. It is this principle that makes it possible in the case of a gas to fix the constitution of the molecule when the ratio in number of the atoms entering into it has been determined by analysis. In the case of solids, where the constitution of the molecule in general cannot be fixed, it is best, as already stated, to write the molecular formula in its simplest form, as $NaAlSi_3O_8$ for albite. The sum of the weights of the atoms present is then taken as the molecular weight.

458. Valence. — The valence of an element is given by a number representing the capacity of its atoms to combine with the atoms of some unit element like hydrogen or chlorine. Thus, using the examples of Art. **456,** in NaCl, since one atom of sodium unites with one of chlorine, its valence is one; or, in other words, it is said to be *univalent*. Further, calcium (as in $CaCl_2$), also barium, etc., are bivalent; aluminium is trivalent; silicon is tetravalent, etc. The valence may be expressed by the number of bonds by which one element in a compound is united to another, thus:

$$Na-Cl, \qquad Ba=Cl_2, \qquad Au\equiv Cl_3, \qquad Sn\equiv Cl_4, \qquad \text{etc.}$$

A considerable number of the elements show a different valence in different compounds. Thus both Sb_2O_3 and Sb_2O_5 are known; also FeO and Fe_2O_3; CuCl and $CuCl_2$. These possible variations are indicated in the following table which gives the valences for the common elements.

Univalent: H, Cl, Br, I, F; Li, Na, K, Rb, Cs, Ag, Hg, Cu, Au.

Bivalent: O, S, Se, Te; Be, Mg, Ca, Sr, Ba, Pb, Hg, Cu, Zn, Co, Ni, Fe, Mn, Cr, C, Sn.

Trivalent: B, Au, Al, Fe, Mn, Cr, Co, Ni, N, P, As, Sb, Bi.

Tetravalent: C, Si, Ti, Zr, Sn, Mn, Pb.

Pentavalent: N, P, As, Sb, V, Bi, Nb, Ta.

459. Chemical Reactions. — When solutions of two chemical substances are brought together, in many cases they react upon each other with the result of forming new compounds out of the elements present; this phenomenon is called a *chemical reaction*. One of the original substances may be a gas, and in many cases similar results are obtained from a liquid and a solid, or less often from two solids.

For example, solutions of sodium chloride (NaCl) and silver nitrate ($AgNO_3$) react on each other and yield silver chloride (AgCl) and sodium nitrate ($NaNO_3$). This is expressed in chemical language as follows:

$$NaCl + AgNO_3 = AgCl + NaNO_3.$$

This is a chemical equation, the sign of equality meaning that equal weights are involved both before and after the reaction.

Again, hydrochloric acid (HCl) and calcium carbonate ($CaCO_3$) yield calcium chloride ($CaCl_2$) and carbonic acid (H_2CO_3); which last breaks up into water (H_2O) and carbon dioxide (CO_2), the last going off as a gas with effervescence. Hence

$$CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2.$$

460. Radicals. — A compound of two or more elements according to their relative valence in which all their bonds are satisfied is said to be *saturated*. This is true of H_2O, or, as it may be written, H—O—H. If, however, one or more bonds is left unsatisfied, the resulting combination of elements is called a *radical*. Thus — O —H, called briefly hydroxyl, is a common radical, having a valence of one, or, in other words, univalent; NH_4 is again a univalent radical; so, too, (CaF), (MgF) or (AlO). Radicals often enter into a compound like a simple element; for example, in ammonium chloride, NH_4Cl, the univalent radical NH_4 plays the same part as the univalent element Na in NaCl. In the chemical composition of mineral species, the commonest radical is hydroxyl (—O—H) already defined. Other examples are (CaF) in apatite (see Art. 471), (MgF) in wagnerite, (AlO) in many basic silicates, etc.

461. Chemical Compound. — A chemical compound is a combination of two or more elements united by the force of chemical attraction. It is always true of it, as before stated (Art. 456), that the elements present are combined in the proportion of their atomic weights or some simple multiples of these. A substance which does not satisfy this condition is not a compound, but only a mechanical mixture.

Examples of the simpler class of compounds are afforded by the *oxides*, or compounds of oxygen with another element. Thus, among minerals we have Cu_2O, cuprous oxide (cuprite); ZnO, zinc oxide (zincite); Al_2O_3, alumina (corundum); SnO_2, tin dioxide (cassiterite); SiO_2, silicon dioxide (quartz); As_2O_3, arsenic trioxide (arsenolite).

Another simple class of compounds are the *sulphides* (with the selenides, tellurides, arsenides, antimonides, etc.), compounds in which sulphur (selenium, tellurium, arsenic, antimony, etc.) plays the same part as oxygen in the oxides. Here belong Cu_2S, cuprous sulphide (chalcocite); ZnS, zinc sulphide (sphalerite); $PbTe$, lead telluride (altaite); FeS_2, iron disulphide (pyrite); Sb_2S_3, antimony trisulphide (stibnite).

462. Acids. — The more complex chemical compounds, an understanding of which is needed in a study of minerals, are classed as acids, bases, and salts; the distinctions between them are important.

An *acid* is a compound of hydrogen, or hydroxyl, with a non-metallic element (as chlorine, sulphur, nitrogen, phosphorus, etc.), or a radical containing these elements. When dissolved in water they all give the positive hydrogen ion and a negative ionic substance such as Cl, SO_4, etc. The hydrogen atoms of an acid may be replaced by metallic atoms; the result being then the formation of a salt (see Art. 464). Acids in general turn blue litmus paper red and have a sharp, sour taste. The following are familiar examples:

HCl, hydrochloric acid,
HNO_3, nitric acid.
H_2CO_3, carbonic acid.
H_2SO_4, sulphuric acid.
H_2SiO_3, metasilicic acid.
H_3PO_4, phosphoric acid.
H_4SiO_4, orthosilicic acid.

It is to be noted that with a given acid element several acids are possible. Thus normal, or orthosilicic, acid is H_4SiO_4, in which the bonds of the element silicon are all satisfied by the hydroxyl (HO). But the removal of one molecule of water, H_2O, from this gives the formula H_2SiO_3, or metasilicic acid.

Acids which, like HNO_3, contain one atom of hydrogen that may be replaced by a metallic atom (*e.g.*, in KNO_3) are called *monobasic*. If, as in H_2CO_3 and H_2SO_4, there are two atoms or a single bivalent atom, (*e.g.*, in $CaCO_3$, $BaSO_4$) the acids are *dibasic*. Similarly, H_3PO_4 is *tribasic*, etc.

Most acids are liquids (or gases), and hence acids are represented very sparingly among minerals; $B(OH)_3$, boric acid (sassolite), is an illustration.

463. Bases. — The *bases*, or hydroxides, as they are also called, are compounds which may be regarded as formed of a metallic element (or radical) and the univalent radical hydroxyl, — (OH); or, in other words, of an oxide with water. Thus potash, K_2O, and water, H_2O, form $2K(OH)$, or potassium hydroxide; also $CaO + H_2O$ similarly give $Ca(OH)_2$, or calcium hydroxide. In general, when soluble in water, bases give an alkaline reaction with turmeric paper or red litmus paper, and they also neutralize an acid, as explained in the next article. Further, the bases yield water on ignition, that is, at a temperature sufficiently high to break up the compound.

Among minerals the bases are represented by the hydroxides, or hydrated oxides, as $Mg(OH)_2$, magnesium hydrate (brucite); $Al(OH)_3$, aluminium hydrate (gibbsite); also, $(AlO)(OH)$, diaspore, etc.

464. Salts. — A third class of compounds are the *salts;* these may be regarded as formed chemically by the reaction of a base upon an acid, or, in other words, by the neutralization of the acid. Thus calcium hydrate and sulphuric acid give calcium sulphate and water:

$$Ca(OH)_2 + H_2SO_4 = CaSO_4 + 2H_2O.$$

Here calcium sulphate is the salt, and in this case the acid, sulphuric acid, is said to be neutralized by the base, calcium hydroxide. It is instructive to compare the formulas of a base, an acid, and the corresponding salt, as follows:

Base, $Ca(OH)_2$; *Acid,* H_2SO_4; *Salt,* $CaSO_4$.

Here it is seen that a salt may be simply described as formed from an acid by the replacement of the hydrogen atom, or atoms, by a metallic element or radical.

465. Typical Salts. — The commonest types of salts represented among minerals are the following:

Chlorides: salts of hydrochloric acid, HCl; as $AgCl$, silver chloride (cerargyrite).

Nitrates: salts of nitric acid, HNO_3; as KNO_3, potassium nitrate (niter).

Carbonates: salts of carbonic acid, H_2CO_3; as $CaCO_3$, calcium carbonate (calcite and aragonite).

Sulphates: salts of sulphuric acid, H_2SO_4; as $CaSO_4$, calcium sulphate (anhydrite).

Phosphates: salts of phosphoric acid, H_3PO_4; as $Ca_3(PO_4)_2$, calcium phosphate.

Silicates: several classes of salts are here included. The most common are the salts of metasilicic acid, H_2SiO_3; as $MnSiO_3$, manganese metasilicate (rhodonite). Also salts of orthosilicic acid, H_4SiO_4; as Mn_2SiO_4, manganese orthosilicate (tephroite).

Numerous other classes of salts are also included among mineral species; their composition, as well as that of complex salts of the above types, is explained in the descriptive part of this work.

466. Normal, Acid, and Basic Salts. — A *neutral* or *normal salt* is one in which the basic element completely neutralizes the acid, or, in other words, one of the type already given as examples, in which *all* the hydrogen atoms of the acid have been replaced by metallic atoms or radicals. Thus, K_2SO_4 is normal potassium sulphate, but $HKSO_4$, on the other hand, is acid potassium sulphate, since in the acid H_2SO_4 only one of the bonds is taken by the basic element potassium. Salts of this kind are called *acid salts.* The formula in such cases may be written * as if the compound consisted of a normal salt and an acid; thus, for the example given, $K_2SO_4 . H_2SO_4$.

A *basic salt* is one in which the acid part of the compound is not sufficient to satisfy all the bonds of the base. Thus malachite is a basic salt — basic carbonate of copper — its composition being expressed by the formula $Cu_2(OH)_2CO_3$. This may be written $CuCO_3 . Cu(OH)_2$, or $(Cu_2)\begin{matrix}=CO_3\\=(OH)_2\end{matrix}$. The majority of minerals consist not of simple salts, as those noted above, but of more or less complex double salts in which several metallic elements are present. Thus common grossular garnet is an orthosilicate containing both calcium and aluminium as bases; its formula is $Ca_3Al_2(SiO_4)_3$.

467. Sulpho-salts. — The salts thus far spoken of are all oxygen salts. There are also others, of analogous constitution, in which sulphur takes the place of the oxygen; they are hence called *sulpho-salts*. Thus normal sulpharsenious acid has the formula H_3AsS_3, and the corresponding silver salt is Ag_3AsS_3, the mineral proustite. Similarly the silver salt of the analogous antimony acid is Ag_3SbS_3, the mineral pyrargyrite. From the normal acids named, a series of other hypothetical acids may be derived, as $HAsS_2$, $H_4As_2S_5$, etc.; these acids are not known to exist, but their salts are important minerals. Thus zinkenite, $PbSb_2S_4$, is a salt of the acid $H_2Sb_2S_4$, and jamesonite, $Pb_2Sb_2S_5$, of the acid $H_4Sb_2S_5$, etc.

468. Water of Crystallization. — As stated in Art. **463**, the hydroxides, or bases, and further basic salts in general, yield water when ignited. Thus calcium hydroxide $Ca(OH)_2$ breaks up on heating into CaO and H_2O, as expressed in the chemical equation

$$2Ca(OH)_2 = 2CaO + H_2O.$$

So also the basic cupric carbonate, malachite, $Cu_2(OH)_2CO_3$, yields water on ignition; and the same is true of the complex basic orthosilicates, like zoisite, whose formula is $(HO)Ca_2Al_3(SiO_4)_3$. It is not to be understood, however, in these or similar cases, that water as such is present in the substance.

On the other hand, there is a large number of mineral compounds which yield water readily when heated, and in which the water molecules are regarded as present as so-called *water of crystallization*. Thus, the formula of gypsum is written

$$CaSO_4 + 2H_2O,$$

and the molecules of water ($2H_2O$) are considered as water of crystallization. So, too, in potash alum, $KAl(SO_4)_2 + 12H_2O$, the water is believed to play the same part.

469. Formulas of Minerals. — The strictly empirical formula expresses the kinds and numbers of atoms of the elements present in the given compound, without attempting to show the way in which it is believed that the atoms are combined. Thus, in the case of zoisite the empirical formula is $HCa_2Al_3Si_3O_{13}$. While not attempting to represent the structural formula (which will not be discussed here), it is convenient in certain cases to indicate the atoms which there is reason to believe play a peculiar relation to each other. Thus the same formula written $(HO)Ca_2Al_3(SiO_4)_3$ shows that it is regarded as a basic orthosilicate, in other words, a basic salt of orthosilicic acid, H_4SiO_4.

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* This early form of writing the composition explains the name often given to the compound, namely, in this case, "bisulphate of potash."

Again, the empirical formula of common apatite is $Ca_5FP_3O_{12}$; but if this is written $(CaF)Ca_4(PO_4)_3$, it shows that it is regarded as a phosphate of the acid H_3PO_4, that is, $H_9(PO_4)_3$, in which the nine hydrogen atoms are replaced by four Ca atoms together with the univalent radical (CaF). In another kind of apatite the radical (CaCl) enters in the same way. Similarly to this the formula of pyromorphite is $(PbCl)Pb_4(PO_4)_3$, of vanadinite $(PbCl)Pb_4(VO_4)_3$.

Further, it is often convenient to employ the method of writing the formulas in vogue under the old dualistic system. For example,

$$CaO \,.\, CO_2 \text{ for } CaCO_3,$$
$$3CaO \,.\, Al_2O_3 \,.\, 3SiO_2 \text{ for } Ca_3Al_2Si_3O_{12},$$
$$3Ag_2S \,.\, Sb_2S_3 \text{ for } Ag_3SbS_3, \text{ etc.}$$

It is no longer believed, however, that the molecular groups CaO, Al_2O_3, etc., actually exist in the molecule of the substance. But in part because these groups are what analysis of the substance affords directly, and in part because so easily retained in the memory, this method of writing is still often used.

470. Calculation of a Formula from an Analysis. — The result of an analysis gives the proportions, in a hundred parts of the mineral, of either the elements themselves, or of their oxides or other compounds obtained in the chemical analysis. In order to obtain the atomic proportions of the elements:

Divide the percentages of the elements by the respective ATOMIC WEIGHTS; or, for those of the oxides: *Divide the percentage amounts of each by their* MOLECULAR WEIGHTS; then *find the simplest ratio in whole numbers for the numbers thus obtained.*

Example. — An analysis of bournonite from Wolfsberg gave C. Bromeis the results under (1) below. These percentages divided by the respective atomic weights, as indicated, give the numbers under (2). Finally the ratio of these numbers gives very nearly 1 : 3 : 1 : 1. Hence the formula derived is $CuPbSbS_3$. The theoretical values called for by the formula are added under (4).

	(1)	(2)	(3)	(4)
Sb	24·34 ÷ 120	= 0·203	1	24·7
S	19·76 ÷ 32	= 0·617	3	19·8
Pb	42·88 ÷ 206·4	= 0·208	1	42·5
Cu	13·06 ÷ 63·2	= 0·207	1	13·0
	100·04			100·0

Second Example. — The mean of two analyses of a garnet from Alaska gave Kountze the results under (1) below. Here, as usual, the percentage amounts of the several molecular groups (SiO_2, Al_2O_3, etc.) are given instead of those of the elements. These amounts divided by the respective molecular weights give the numbers under (2). In this case the amounts of the protoxides are taken together and the ratio thus obtained is 3·09 : 1 : 2·92, which corresponds approximately to the formula $3FeO.Al_2O_3.3SiO_2$, or $Fe_3Al_2(SiO_4)_3$. The magnesium in this garnet would ordinarily be explained by the presence of the pyrope molecule ($Mg_3Al_2[SiO_4]_3$) together with the simple almandite molecule whose composition is given above.

	(1)	(2)		(3)
SiO_2	39·29 ÷ 60	= 0·655		3·09
Al_2O_3	21·70 ÷ 102	= 0·212		1
Fe_2O_3	*tr.*			
FeO	30·82 ÷ 71·9	= 0·429	0·619	2·92
MnO	1·51 ÷ 70·8	= 0·022		
MgO	5·26 ÷ 40	= 0·132		
CaO	1·99 ÷ 55·9	= 0·036		
	100·57			

It is necessary, when very small quantities only of certain elements (as MnO, MgO, CaO above) are present, to neglect them in the final formula, reckoning them in with the elements which they replace, that is, with those of the same quantivalence. The degree of correspondence between the analysis and the formula deduced, if the latter is correctly assumed, depends entirely upon the accuracy of the former.

471. Isomorphism. — Chemical compounds which have an analogous composition and a closely related crystalline form are said to be *isomorphous*. This phenomenon, called ISOMORPHISM, was first clearly brought out by Mitscherlich.

Many examples of groups of isomorphous compounds will be found among the minerals described in the following pages. Some examples are mentioned here in order to elucidate the subject.

In the brief discussion of the periodic classification of the chemical elements of Art. 455, attention has been called to the prominent groups among the elements which form analogous compounds. Thus calcium, barium, and strontium, and also lead, form the two series of analogous compounds,

Aragonite Group		Barite Group
$CaCO_3$, aragonite.	Also	$CaSO_4$, anhydrite.
$BaCO_3$, witherite.		$BaSO_4$, barite.
$SrCO_3$, strontianite.		$SrSO_4$, celestite.
$PbCO_3$, cerussite,		$PbSO_4$, anglesite.

Further, the members of each series crystallize in closely similar forms. The carbonates are orthorhombic, with axial ratios not far from one another; thus the prismatic angle approximates to 60° and 120°, and corresponding to this they all exhibit pseudo-hexagonal forms due to twinning. The sulphates also form a similar orthorhombic series, and though anhydrite deviates somewhat widely, the others are close together in angle and in cleavage.

Again, calcium, magnesium, iron, zinc, and manganese form a series of carbonates with analogous composition as shown in the list of the species of the *Calcite Group* given on p. 437. This table brings out clearly the close relation in form between the species named.

Further it is also generally true with an isomorphous series that the various molecules may enter in greater or less degree into the constitution of one of the members of the series without causing any marked change in the crystal characters. For instance, in the Calcite Group, calcite itself may contain small percentages of $MgCO_3$, $FeCO_3$ and $MnCO_3$. These different molecules may assume in the crystal structure of the mineral the same functions as the corresponding amounts of $CaCO_3$ which they have replaced. The molecules of magnesite and siderite, $MgCO_3$ and $FeCO_3$, may replace each other in any proportion and the same is true with siderite and rhodochrosite, $MnCO_3$. Various intermediate mixtures of these latter molecules have been described and given distinctive names to which definite formulas have been assigned. It is doubtful, however, if these compounds have any real existence but merely represent certain points in the complete isomorphous series that lies between the end members. Dolomite, $CaMg(CO_3)_2$, on the other hand, is a definite compound and not an isomorphous mixture of $CaCO_3$ and $MgCO_3$. It may, however, contain varying amounts of $FeCO_3$, $MnCO_3$ and also an excess of $CaCO_3$ or $MgCO_3$, all of which enter the regular molecule in the form of isomorphous replacements.

The *Apatite Group* forms another valuable illustration since in it are represented the analogous compounds, apatite and pyromorphite, both phosphates, but respectively phosphates of calcium and lead; also the analogous lead compounds pyromorphite, mimetite, and vanadinite respectively lead phosphate, lead arsenate, and lead vanadate. Further, in all these compounds the radical (RCl) or (RF) enters in the same way (see Art. **469**). Thus the formulas for the two kinds of apatite and that for pyromorphite are as follows:

$$(CaF)Ca_4(PO_4)_3, \qquad (CaCl)Ca_4(PO_4)_3, \qquad (PbCl)Pb_4(PO_4)_3.$$

Some of the more important isomorphous groups are mentioned below. For a discussion of them, as well as of many others that might be mentioned here, reference must be made to the descriptive part of this work.

Isometric System. — The Spinel group, including spinel, $MgAl_2O_4$; also magnetite, chromite, franklinite, gahnite, etc. The Galena group, as galena, PbS; argentite, Ag_2S, etc. The Garnet group, as grossularite, $Ca_3Al_2Si_3O_{12}$, etc.

Tetragonal System. — Rutile group, including rutile, TiO_2; cassiterite, SnO_2. The Scheelite group, including scheelite, $CaWO_4$; stolzite, $PbWO_4$; wulfenite, $PbMoO_4$.

Hexagonal System. — Apatite group, already mentioned, including apatite, pyromorphite, mimetite, and vanadinite. Corundum group, corundum, Al_2O_3; hematite, Fe_2O_3. Calcite group, already mentioned. Phenacite group, etc.

Orthorhombic System. — Aragonite group, and Barite group, both mentioned above. Chrysolite group, $(Mg,Fe)_2SiO_4$; Topaz group, etc.

Monoclinic System. — Copperas group, including melanterite, $FeSO_4 + 7H_2O$; bieberite, $CoSO_4 + 7H_2O$, etc. Pyroxene and Amphibole groups, and the Mica group.

Monoclinic and Triclinic Systems. — Feldspar group.

472. Isomorphous Mixtures. — It is important to note that the intermediate compounds in the case of an isomorphous series, such as those spoken of in the preceding article, often show a distinct gradation in crystalline form, and more particularly in physical characters (*e.g.*, specific gravity, optical properties, etc.). This is illustrated by the species of the calcite group already referred to; also still more strikingly by the group of the triclinic feldspars as fully discussed under the description of that group. See further Art. **424**.

The feldspars also illustrate two other important points in the subject, which must be briefly alluded to here. The triclinic feldspars have been shown by Tschermak to be isomorphous mixtures of the end compounds in varying proportions:

$$\text{Albite, } NaAlSi_3O_8. \qquad \text{Anorthite, } CaAl_2Si_2O_8.$$

Here it is seen that these compounds have not an analogous composition in the narrow sense previously illustrated, and yet they are isomorphous and form an isomorphous series. Other examples of this are found among the pyroxenes, the scapolites, etc.

Further, the Feldspar group in the broader sense includes several other species, conspicuously the monoclinic orthoclase, $KAlSi_3O_8$, which, though belonging to a different system, still approximates closely in form to the triclinic species.

473. Variation in Composition of Minerals. Isomorphous Replacement and Solid Solution. — The idea that a mineral must rigidly conform in its chemical composition to a theoretical composition derived from its formula can no longer be strictly held. It is true that the majority of minerals do show a close correspondence to that theory, commonly within the limits of possible errors in the analyses. On the other hand, many minerals show slight and certain ones considerable variations from their theoretical compositions. These variations can usually be explained by the principle of isomorphism. An instructive example is the case of sphalerite. Note in the analyses quoted below how the percentages of zinc diminish and those of iron correspondingly increase. It is evident from these analyses that iron, and in a much smaller degree other metals, may enter into the chemical compound and while replacing the zinc perform the same function as it, in the crystalline structure of the mineral. The iron is therefore spoken of as being isomorphous with the zinc or the iron sulphide molecule as isomorphous with the zinc sulphide molecule. There is no definite ratio between the amounts of the iron and zinc that may be present but there is a constant ratio (1 : 1) between the sum of the atoms of the metals and the atoms of sulphur. That is, although the composition may vary, the atomic ratios and the crystalline structure remain constant. In some cases this interchange between elements or radicals may be complete, in other cases there may be distinct limitations to the amount by which any element or radical may be replaced by another. For instance in sphalerite the maximum percentage of the isomorphous iron seems to be about 16 to 18 per cent.

Colorless Sphalerite		Brown Sphalerite		Black Sphalerite	
S	32.93	S	33.36	S	33.25
Zn	66.69	Zn	63.36	Zn	50.02
Fe	0.42	Fe	3.60	Fe	15.44
	100.04		100.32	Cd	0.30
				Pb	1.01
					100.02

Further, we have cases where a compound may, in a certain sense, dissolve another unrelated substance and form what is known as a *solid solution*. This kind of phenomenon is well recognized among artificial salts and has recently been definitely proved with certain minerals. For instance, it has been shown experimentally that the artificial iron sulphide, FeS, corresponding to pyrrhotite, can dissove an excess of sulphur up to about 6 per cent. Natural pyrrhotite always contains an excess of sulphur over that required by the formula, FeS, and various formulas such as Fe_7S_8, Fe_nS_{n+1}, etc., have been assigned to the mineral. This extra sulphur in the mineral varies in amount but also has as its maximum about 6 per cent. In view of the experimental data there is no doubt but that pyrrhotite should be considered as the monosulphide of iron containing varying small amounts of excess sulphur in the form of a solid solution.

Another case of solid solution is undoubtedly shown by nephelite which commonly contains a small excess of SiO_2. It is very probable that further investigation will show that many minerals have this power of holding in solid solution small amounts of foreign substances and that many hitherto inexplicable discrepancies in their analyses may be explained in this way. Such an assumption should not be made, however, without convincing proof of its probability, since many analytical discrepancies are undoubtedly due to either faulty analyses or to impure material.

474. Colloidal Minerals or Mineral Gels.* — It has been recognized recently that our amorphous hydrated minerals frequently do not conform in their analyses to the usually accepted formulas and cannot be regarded in the strict sense as definite chemical compounds. They show rather the properties of solid colloids or as they are commonly called *mineral gels*. A colloidal solution may be conceived as being intermediate in its characters between a true solution and the case where the mineral material is definitely in suspension in a liquid. It is probable that all gradations between these two extremes may occur. The mineral gels, or hydrogels, as they are sometimes called, since water is the liquid involved, are apparently formed from such colloidal solutions by some process of coagulation. They are considered therefore to consist of a micro-heterogeneous mixture of excessively minute particles of mineral material and water.

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* For a résumé of the subject of gel minerals and a complete bibliography reference is made to articles by Marc and Himmelbauer, Fortschritte Min. Krist. Pet., 3, 11, 33, 1913.

These mineral gels are formed at low temperatures and pressures and are characteristically found among the products of rock weathering and in the oxidized zone of ore deposits. Some of them also occur in hot spring deposits. These minerals ordinarily assume botryoidal, reniform or stalactitic shapes, although, when the conditions of formation do not permit free growth, they may be earthy or dendritic. Frequently a mineral originally colloidal may become more or less crystalline in character through a molecular rearrangement and develop a fibrous or foliated structure. These have been designated as *meta-colloids*.

One important character of the gel minerals is their power to adsorb foreign materials. If through some change in condition one of these hydrogels should lose a part of its water content the remaining material would have a finely divided and porous structure exactly adapted to exert a strong power of adsorption. Consequently, although in many cases the main mass of the mineral may have a composition closely similar to some definite crystallized mineral, it will commonly show a considerable range in composition due both to the non-molecular relations of the contained water and to this secondary adsorption. Common mineral gels or substances derived from them are opal, bauxite, psilomelane, various members of the phosphate and arsenate groups, etc. As suggested above, gel varieties of minerals that occur also in crystalline forms are thought to exist. For example some authors speak of bauxite as the gel form of hydrargillite, stilpnosiderite as the gel form of goethite, chrysocolla of dioptase, and further give new names, such as gelvariscite, gelpyrophyllite, etc., to the gel phases of the corresponding crystalline minerals.

475. Dimorphism. Isodimorphism. — A chemical compound, which crystallizes in two forms genetically distinct, is said to be *dimorphous;* if in three, *trimorphous*, or in general *pleomorphous*. This phenomenon is called DIMORPHISM OR PLEOMORPHISM.

An example is given by the compound calcium carbonate ($CaCO_3$), which is dimorphous: appearing as calcite and as aragonite. As *calcite* it crystallizes in the rhombohedral class of the hexagonal system, and, unlike as its many crystalline forms are, they may be all referred to the same fundamental axes, and, what is more, they have all the same cleavage and the same specific gravity (2·7) and, of course, the same optical characters. As *aragonite,* calcium carbonate appears in orthorhombic crystals, whose optical characters are entirely different from those of calcite; moreover, the specific gravity of aragonite (2·9) is higher than that of calcite (2·7).

Many other examples might be given: Titanium dioxide (TiO_2) is trimorphous, the species being called *rutile*, tetragonal ($c = 0{\cdot}6442$), G. = 4·25; *octahedrite,* tetragonal ($c = 1{\cdot}778$), G. = 3·9; and *brookite*, orthorhombic, G. = 4·15. Carbon appears in two forms, in diamond and graphite. Other familiar examples are pyrite and marcasite (FeS_2), sphalerite and wurtzite (ZnS), etc.

When two or more analogous compounds are at the same time isomorphous and dimorphous, they are said to be *isodimorphous*, and the phenomenon is called ISODIMORPHISM. An example of this is given in the Pyrite and Marcasite groups described later. Thus we have in the isometric Pyrite Group, pyrite, FeS_2, smaltite, $CoAs_2$; in the orthorhombic Marcasite Group, marcasite, FeS_2, safflorite, $CoAs_2$, etc.

476. Chemical and Microchemical Analysis. — The analysis of minerals is a subject treated of in chemical works, and need not be touched upon here except so far as to note the convenient use of certain qualitative methods, as described in the later part of this chapter.

Of more importance are the *microchemical* methods applicable to sections under the microscope and often yielding decisive results with little labor. This subject has been particularly developed by Boricky, Haushofer, Behrens, Streng, and others. Reference is made to the discussion by Rosenbusch. (Mikr. Phys., 1904, p. 435 *et seq.*), to Johannsen (Manual of Pet. Methods, 559, *et seq.*, including a bibliography). Microchemical methods used upon polished surfaces of opaque minerals are described by Murdock (Micro. Deter. Opaque Min., 1916) and by Davy-Farnham (Micro. Exam. of the Ore Min., 1920).

477. Mineral Synthesis. — The occurrence of certain mineral compounds (*e.g.*, the chrysolites) among the products of metallurgical furnaces has long been noted. But it has only been in recent years that the formation of artificial minerals has been made the subject of minute systematic experimental study. In this direction the French chemists have been particularly successful, and now it may be stated that the majority of common minerals — quartz, the feldspars, amphibole, mica, etc. — have been obtained in crystallized form. Even the diamond has been formed in minute crystals by Moissan. These studies are obviously of great importance particularly as throwing light upon the method of formation of minerals in nature. The chief results of the work thus far done are given in the volumes mentioned in the Introduction, p. 4.

478. Alteration of Minerals. Pseudomorphs. — The chemical alteration of mineral species under the action of natural agencies is a subject of great importance and interest, particularly when it results in the change of the original composition into some other equally definite compound. A crystallized mineral which has thus suffered change so that its form no longer belongs to its chemical composition has already been defined (Art. **273**, p. 183) as a *pseudomorph*. It remains to describe more fully the different kinds of pseudomorphs. Pseudomorphs are classed under several heads:

1. Pseudomorphs by *substitution*.

2. Pseudomorphs by simple *deposition*, and either by (*a*) *incrustation* or (*b*) *infiltration*.

3. Pseudomorphs by *alteration;* and these may be altered
    (*a*) without a change of composition, by *paramorphism;*
    (*b*) by the loss of an ingredient;
    (*c*) by the assumption of a foreign substance;
    (*d*) by a partial exchange of constitutents.

1. The first class of pseudomorphs, by *substitution*, embraces those cases where there has been a gradual removal of the original material and a corresponding and simultaneous replacement of it by another, without, however, any chemical reaction between the two. A common example of this is a piece of fossilized wood, where the original fiber has been replaced entirely by

silica. The first step in the process was the filling of the pores and cavities by the silica in solution, and then as the woody fiber, by gradual decomposition, disappeared the silica further took its place. Other examples are quartz after fluorite, calcite, and many other species; cassiterite after orthoclase; native copper after aragonite, etc.

2. Pseudomorphs by *incrustation* form a less important class. Such are the crusts of quartz formed over fluorite. In most cases the removal of the original mineral has gone on simultaneously with the deposition of the second, so that the resulting pseudomorph is properly one of substitution. In pseudomorphs by *infiltration* a cavity made by the removal of a crystal has been filled by another mineral.

3. The third class of pseudomorphs, by *alteration*, includes a considerable proportion of the observed cases, of which the number is very large. Conclusive evidence of the change which has gone on is often furnished by a nucleus of the original mineral in the center of the altered crystal — *e.g.*, a kernel of cuprite in a pseudomorphous octahedron of malachite; also of chrysolite in a pseudomorphous crystal of serpentine, etc.

(*a*) An example of *paramorphism* — that is, of a change in molecular constitution without change of chemical substance — is furnished by the change of aragonite to calcite (both $CaCO_3$) at a certain temperature; also the *paramorphs* of rutile after brookite (both TiO_2) from Magnet Cove, Arkansas.

(*b*) An example of the pseudomorphs in which alteration is accompanied by a loss of ingredients is furnished by crystals of native copper in the form of cuprite.

(*c*) In the change of cuprite to malachite — *e.g.*, the familiar crystals from Chessy, France — an instance is afforded of the assumption of an ingredient — viz., carbon dioxide (and water). Pseudomorphs of gypsum after anhydrite occur where there has been an assumption of water alone.

(*d*) A partial exchange of constituents — in other words, a loss of one and gain of another — takes place in the change of feldspar to kaolin, in which the potash silicate disappears and water is taken up; pseudomorphs of limonite after pyrite or siderite, of chlorite after garnet, pyromorphite after galena, are other examples.

The chemical processes involved in such changes open a wide and important field for investigation. Their study has served to throw much light on the chemical constitution of mineral species and the conditions under which they have been formed. For the literature of the subject see the Introduction, p. 4 (Blum, Bischof, Roth, etc.).

CHEMICAL EXAMINATION OF MINERALS

479. The complete investigation of the chemical composition of a mineral includes, first, the identification of the elements present by qualitative analysis, and, second, the determination of the relative amounts of each by quantitative analysis, from which last the formula can be calculated. Both processes carried out in full call for the equipment of a chemical laboratory. An approximate qualitative analysis, however, can, in many cases, be made quickly and simply with few conveniences. The methods employed involve either (*a*) the use of acids or other reagents "in the wet way," or (*b*) the use of the blowpipe, or of both methods combined. Some practical instructions will be given applying to both cases.

EXAMINATION IN THE WET WAY

480. Reagents, etc. — The most commonly employed chemical reagents are the three mineral acids, hydrochloric, nitric, and sulphuric acids. To these may be added ammonium hydroxide, also solutions of barium chloride, silver nitrate, ammonium molybdate, ammonium oxalate; finally, distilled water in a wash-bottle.

A few test-tubes are needed for the trials and sometimes a porcelain dish with a handle called a casserole; further, a glass funnel and filter-paper. The Bunsen gas-burner (p. 330) is the best source of heat, though an alcohol lamp may take its place. It is unnecessary to remark that the use of acids and the other reagents requires much care to avoid injury to person or clothing.

In testing the powdered mineral with the acids, the important points to be noted are: (1) the degree of solubility, and (2) the phenomena attending entire or partial solution; that is, whether (*a*) a solution is obtained quietly, without effervescence, and, if so, what its color is; or (*b*) a gas is evolved, producing effervescence; or (*c*) an insoluble constituent is separated out.

481. Solubility. — In testing the degree of solubility hydrochloric acid is most commonly used, though in the case of many metallic minerals, as the sulphides and compounds of lead and silver, nitric acid is required. Less often sulphuric acid and aqua regia (nitro-hydrochloric acid) are resorted to.

The trial is usually made in a test-tube, and in general the fragment of mineral to be examined should be first carefully pulverized in an agate mortar. In most cases the heat of the Bunsen burner must be employed.

(*a*) Many minerals are completely *soluble without effervescence;* among these are some of the oxides, as hematite, limonite, göthite, etc.; some sulphates, many phosphates and arsenates, etc. Gold and platinum are soluble only in aqua regia or nitro-hydrochloric acid.

A yellow solution is usually obtained if much iron is present; a blue or greenish blue solution (turning deep blue on the addition of ammonium hydroxide in excess) from compounds of copper; pink or pale rose from cobalt, etc.

(*b*) *Solubility with effervescence* takes place when the mineral loses a gaseous ingredient, or when one is generated by the mutual reaction of acid and mineral. Most conspicuous here are the *carbonates*, all of which dissolve with effervescence, giving off the odorless gas *carbon dioxide* (CO_2), though some of them only when pulverized, or, again, on the addition of heat. In applying this test dilute hydrochloric acid is employed.

Hydrogen sulphide (H_2S) is evolved by some sulphides when dissolved in hydrochloric acid: this is true of sphalerite, stibnite, etc. This gas is readily recognized by its offensive odor.

Chlorine is evolved by oxides of manganese and also chromic and vanadic acid salts when dissolved in hydrochloric acid.

Nitrogen dioxide (NO_2) is given off, in the form of red suffocating fumes, by many metallic minerals, and also some of the lower oxides (cuprite, etc.), when treated with nitric acid.

(*c*) The *separation of an insoluble ingredient* takes place: With many silicates, the *silica* separating sometimes as a fine powder, and again as a jelly; in the latter case the mineral is said to *gelatinize* (sodalite, analcite). In order to test this point the finely pulverized silicate is digested with strong hydrochloric acid, and the solution afterward slowly evaporated nearly to dryness. With a considerable number of silicates the gelatinization takes place only after the mineral has been previously fused; while some others, which ordinarily gelatinize, are rendered insoluble by ignition.

With many sulphides (as pyrite) a separation of *sulphur* takes place when they are treated with nitric acid.

Some compounds of titanium and tungsten are decomposed by hydrochloric acid with the separation of the oxides of the elements named (TiO_2, WO_3). The same is true of salts of molybdic and vanadic acids, only that here the oxides are soluble in an excess of the acid.

Compounds containing silver, lead, and mercury give with hydrochloric acid insoluble residues of the *chlorides*. These compounds are, however, soluble in nitric acid.

When compounds containing tin are treated with nitric acid, the *tin dioxide* (SnO_2) separates as a white powder. A corresponding reaction takes place under similar circumstances with minerals containing arsenic and antimony.

Insoluble Minerals. — A large number of minerals are not sensibly attacked by any of the acids. Among these may be named the following oxides: corundum, spinel, chromite, diaspore, rutile, cassiterite, quartz; also cerargyrite; many silicates, titanates, tantalates, and niobates; some of the sulphates, as barite, celestite; many phosphates, as xenotime, lazulite, childrenite, amblygonite; also the borate, boracite.

482. Examination of the Solution. — If the mineral is difficultly, or only partially, soluble, the question as to solubility or insolubility is not always settled at once. Partial solution is often shown by the color given to the liquid, or more generally by the precipitate yielded, for example, on the addition of ammonium hydroxide to the liquid filtered off from the remaining powder. The further examination of the solution yielded, whether from partial or complete solution, after the separation by filtration of any insoluble residue, requires the systematic laboratory methods of qualitative analysis.

It may be noted, however, that in the case of sulphates the presence of *sulphur* is shown by the precipitation of a heavy white powder of barium sulphate ($BaSO_4$) when barium chloride is added. The presence of *silver* in solution is shown by the separation of a white curdy precipitate of silver chloride ($AgCl$) upon the addition of any chlorine compound; conversely, the same precipitate shows the presence of *chlorine* when silver nitrate is added to the solution.

Again, *phosphorus* may be detected if present, even in small quantity, in a nitric acid solution of a mineral by the fine yellow powder which separates, sometimes after standing, when ammonium molybdate has been added.

EXAMINATION BY MEANS OF THE BLOWPIPE *

483. The use of the blowpipe, in skilled hands, gives a quick method of obtaining a partial knowledge of the qualitative composition of a mineral. The apparatus needed includes the following articles:

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* The subject of the blowpipe and its use is treated very briefly in this place. The student who wishes to be fully informed not only in regard to the use of the various instruments, but also as to all the valuable reactions practically useful in the identification of minerals, should consult a manual on the subject. The Brush-Penfield Manual of Determinative Mineralogy, with an introduction on Blowpipe Analysis, is particularly to be recommended.

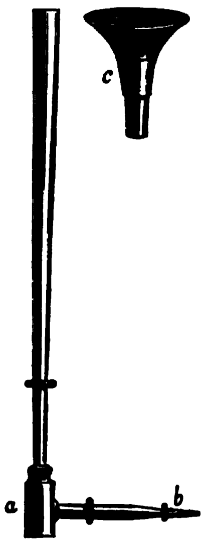
Blowpipe, lamp, forceps, preferably with platinum points, platinum wire, charcoal, glass tubes; also a small hammer with sharp edges, a steel anvil an inch or two long, a horseshoe magnet, a small agate mortar, a pair of cutting pliers, a three-cornered file.

Further, test-paper, both turmeric and blue litmus paper; a little pure tin-foil; also in small wooden boxes the fluxes: borax (sodium tetraborate), soda (anhydrous sodium carbonate), salt of phosphorus or microcosmic salt (sodium-ammonium phosphate), acid potassium sulphate ($HKSO_4$); also a solution of cobalt nitrate in a dropping bulb or bottle; further, the three acids mentioned in Art. **480.**

484. Blowpipe and Lamp. — A good form of *blowpipe* is shown in Fig. 622. The air-chamber, at *a*, is essential to stop the condensed moisture of the breath, the tip (*b*), which is removable, is usually of brass, (*c*) is a removable mouthpiece which may or may not be used as preferred.

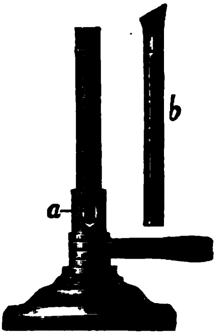
The most convenient form of *lamp* is that furnished by an ordinary Bunsen gas-burner * (Fig. 623), provided with a tube, *b*, which when inserted cuts off the air supply at *a*; the gas then burns at the top with the usual yellow flame. This flame should be one to one and a half inches high. The tip of the blow-pipe is held near (or just within the flame, see beyond), and the air blown through it causes the flame to take the shape shown in Fig. 625.

622



It is necessary to learn to blow *continuously*, that is, to keep up a blast of air from the compressed reservoir in the mouth-cavity while respiration is maintained through the nose. To accomplish this successfully and at the same time to produce a clear flame without unnecessary fatiguing effort calls for some practice.

623



When the tube, *b*, is removed, the gas burns with a colorless flame and is used for heating glass tubes, test-tubes, etc.

485. Forceps. Wire. — The *forceps* (Fig. 624) are made of steel, nickel-plated, and should have a spring strong enough to support firmly the small fragment of mineral between the platinum points at *d*. The steel points at the other end are used to pick up small pieces of minerals, but must not be inserted in the flame. Care must be taken not to injure the platinum by allowing it to come in contact with the fused mineral, especially if this contains antimony, arsenic, lead, etc. Cheaper forceps, made of steel wire, etc., while not so convenient, will also serve reasonably well.

A short length of fairly stout platinum wire to be used in the making of bead tests should be available. A similar length of finer wire for making flame tests is also desirable.

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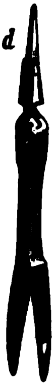
* Instead of this, a good stearin candle will answer, or an oil flame with flat wick.

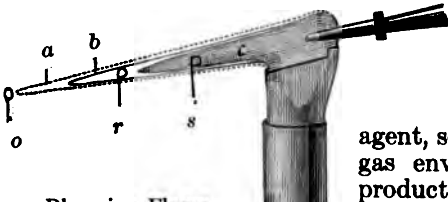
486. Charcoal. — The *charcoal* employed should not snap and should yield but little ash; the kinds made from basswood, pine or willow are best. It is most conveniently employed in rectangular pieces, say four inches long, an inch wide, and three-quarters of an inch in thickness. The surface must always be perfectly clean before each trial.

487. Glass Tubes. — The glass tubes should be preferably of two grades; a hard glass tubing with about 5 mm. interior diameter to be cut in five inch lengths and used in open tube tests and a soft glass tubing with about 3 mm. interior diameter to be in about six inch lengths, each length yielding two closed tubes.

624



625



Blowpipe Flame

488. Blowpipe Flame. — The blowpipe flame, shown in Fig. 625, consists of three cones: an inner of a blue color, *c*, a second pale violet cone, *b*, and an outer invisible cone, *a*. The cone *c* consists of unburned gas mixed with air from the blowpipe. There is no combustion in this cone and therefore no heat. The cone *b* is the one in which combustion is taking place. This cone contains carbon monoxide which is a strong reducing agent, see below. Cone *a* is merely a gas envelope composed of the final products of combustion, CO_2 and H_2O. The heat is most intense near the tip of the cone *b*, and the mineral is held at this point when its *fusibility* is to be tested.

The point *o*, Fig. 625, is called the OXIDIZING FLAME (O.F.); it is characterized by the excess of the oxygen of the air and has hence an *oxidizing* effect upon the assay. This flame is best produced when the jet of the blowpipe is inserted a very little in the gas flame; it should be entirely non-luminous.

The cone *b* is called the REDUCING FLAME (R.F.); it is characterized by the excess of the carbon or hydrocarbons of the gas, which at the high temperature present tend to combine with the oxygen of the mineral brought into it (at *r*), or, in other words, *to reduce* it. The best reducing flame is produced when the blowpipe is held a little distance from the gas flame; it should retain the yellow color of the latter on its upper edge.

489. Methods of Examination. — The blowpipe investigation of minerals includes their examination, (1) in the forceps, (2) in the closed and the open tubes, (3) on charcoal or other support, and (4) with the fluxes on the platinum wire.

1. EXAMINATION IN THE FORCEPS

490. Use of the Forceps. — Forceps are employed to hold the fragment of the mineral while a test is made as to its fusibility; also when the presence of a volatile ingredient which may give the flame a characteristic color is tested for, etc.

The following practical points must be regarded: (1) Metallic minerals, especially those containing arsenic or antimony, which when fused might injure the platinum of the forceps, should first be examined on charcoal;* (2) the fragment taken should be thin, and as small as can conveniently be held, with its edge projecting well beyond the points; (3) when decrepitation takes place, the heat must be applied slowly, or, if this does not prevent it, the mineral may be powdered and a paste made with water, thick enough to be held in the forceps or on the platinum wire; or the paste may, with the same end in view, be heated on charcoal; (4) the fragment whose fusibility is to be tested must be held in the hottest part of the flame, just beyond the extremity of the blue cone.

491. Fusibility. — All grades of fusibility exist among minerals, from those which fuse in large fragments in the flame of the candle (stibnite, see below) to those which fuse only on the thinnest edges in the hottest blowpipe flame (bronzite); and still again there are a considerable number which are entirely infusible (*e.g.*, corundum).

The exact determination of the temperature of fusion is not easily accomplished (cf Art. **431** p. 304), and for purposes of determination of species it is unnecessary. The approximate *relative* degree of fusibility is readily fixed by referring the mineral to the following scale, suggested by von Kobell:

1. Stibnite.
2. Natrolite (or Chalcopyrite).
3. Almandite Garnet.
4. Actinolite.
5. Orthoclase.
6. Bronzite.

492. In connection with the trial of fusibility, the following phenomena may be observed: (*a*) *coloration* of the flame (see Art. **493**); (*b*) *swelling up* (stilbite), or *exfoliation* of the mineral (vermiculite); or (*c*) *glowing* without fusion (calcite); and (*d*) *intumescence*, or a spirting out of the mass as it fuses (scapolite).

The color of the mineral after ignition is to be noted; and the nature of the fused mass is also to be observed, whether a clear or blebby glass is obtained, or a black slag; also whether the bead or residue is magnetic or not (due to iron, less often nickel, cobalt), etc.

The ignited fragment, if nearly or quite infusible, may be moistened with the cobalt solution and again ignited, in which case, if it turns *blue*, this indicates the presence of aluminium (as with cyanite, topaz, etc.); but note that zinc silicate (calamine) also assumes a blue color. If it becomes *pink*, this indicates a compound of magnesium (as brucite).

Also, if not too fusible, it may, after treatment in the forceps, be placed upon a strip of moistened turmeric paper, in which case an *alkaline* reaction proves the presence of an alkali, sodium, potassium; or an alkaline earth, calcium, barium, strontium.

493. Flame Coloration. — The color often imparted to the outer blowpipe flame, while the mineral held in the forceps is being heated, makes possible the identification of a number of the elements.

The colors which may be produced, and the substances to whose presence they are due, are as follows:

Color	**Substance**
Carmine-red......................	Lithium.
Purple-red......................	Strontium.
Orange-red......................	Calcium.
Yellow......................	Sodium.
Yellowish green..................	Barium.
Siskine-green..................	Boron.

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* Arsenic, antimony, and easily reducible metals like lead, also copper, form more or less fusible alloys with platinum.

Emerald-green	Oxide of copper.
Bluish green	Phosphoric acid (phosphates).
Greenish blue	Antimony.
Whitish blue	Arsenic.
Azure-blue	Chloride of copper; also selenium.
Violet	Potassium.

A yellowish green flame is also given by the oxide or sulphide of molybdenum; a bluish green flame (in streaks) by zinc; a pale bluish flame by tellurium; a blue flame by lead.

494. Notes. — The presence of soda, even in small quantities, produces a yellow flame, which (except in the spectroscope) more or less completely masks the coloration of the flame due to other substances, *e.g.*, potassium. A filter of blue glass held in front of the flame will shut out the monochromatic yellow of the sodium flame and allow the characteristic violet color of the potassium to be observed. Silicates are often so difficultly decomposed that no distinct color is obtained even when the substance is present; in such cases (*e.g.*, potash feldspar) the powdered mineral may be fused on the platinum wire with an equal volume of gypsum, when the flame can be seen (at least through blue glass). Again, a silicate like tourmaline fused with a mixture of fluorite and acid potassium sulphate yields the characteristic green flame of boron. Phosphates and borates give the green flame in general best when they have been pulverized and moistened with sulphuric acid. Moistening with hydrochloric acid makes the coloration in many cases (as with the carbonates of calcium, barium, strontium) more distinct.

2. HEATING IN THE CLOSED AND OPEN TUBES

495. The tubes are useful chiefly for examining minerals containing volatile ingredients, given off at the temperature of the gas flame.

In the case of the *closed tube*, the heating goes on practically uninfluenced by the air present, since this is driven out of the tube in the early stages of the process. In the *open tube*, on the other hand, a continual stream of hot air, that is, of hot oxygen, passes over the assay, tending to produce oxidation and hence often materially changing the result.

496. Closed Tube. — A small fragment is inserted, or a small amount of the powdered mineral — in this case with care not to soil the sides of the tube — and heat is applied by means of the ordinary Bunsen flame. The presence of a volatile ingredient is ordinarily shown by the deposit, or *sublimate*, upon the tube at some distance above the assay where the tube is relatively cool.

Independent of this, other phenomena may be noted, namely: *decrepitation*, as shown by fluorite, calcite, etc.; *glowing*, as exhibited by gadolinite; *phosphorescence*, of which fluorite is an example; *change of color* (limonite), and here the color of the mineral should be noted both when hot, and again after cooling; *fusion;* giving off *oxygen*, as mercuric oxide; yielding *acid* or *alkaline vapors*, which should be tested by inserting a strip of moistened litmus or turmeric paper in the tube.

Of the *sublimates* which form in the tube, the following are those with which it is most important to be familiar:

Substance	**Sublimate in the Closed Tube**
Water (H_2O)	Colorless liquid drops.
Sulphur (S)	Red to deep yellow, liquid; pale yellow, solid.
Tellurium dioxide (TeO_2)	Pale yellow to colorless, liquid; colorless or white, solid.
Arsenic sulphide (As_2S_3)	Dark red, liquid; reddish yellow, solid.
Antimony oxysulphide (Sb_2S_2O)	Black to reddish brown on cooling, solid.
Arsenic (As)	Black, brilliant metallic to gray crystalline, solid
Mercury sulphide (HgS)	Deep black, red when rubbed very fine.
Mercury (Hg)	Gray metallic globules.

In addition to the above: Tellurium gives black fusible globules; selenium the same, but in part dark red when very small; the chloride of lead and oxides of arsenic and antimony give white solid sublimates.

497. Open Tube. — The small fragment is placed in the tube about an inch from the lower end, the tube being slightly inclined (say 20°), but not enough to cause the mineral to slip out, and heat applied beneath. The current of air passing upward through the tube during the heating process has an oxidizing effect. The special phenomena to be observed are the formation of a *sublimate* and the *odor* of the escaping gases. The acid or alkaline character of the vapors is tested for in the same way as with the closed tube. The most common gas to be obtained in this way is sulphur dioxide, SO_2, when sulphides are being oxidized. This gas is to be recognized by its irritating, pungent odor and its acid reaction upon moistened blue litmus paper.

The more important sublimates are as follows:

Substance	Sublimate in the Open Tube
Arsenic trioxide (As_2O_3)......	White, crystalline, volatile.
Antimony antimonate (Sb_2O_4)	Straw-yellow, hot; white, cold. Infusible, non-volatile, amorphous, settling along bottom of tube. Obtained from compounds containing sulphur as stibnite, also the sulphantimonites (*e.g.*, bournonite) as dense white fumes. Usually accompanied by the following:
Antimony trioxide (Sb_2O_3)...	White, crystalline, slowly volatile, forming as a ring on walls of tube.
Tellurium dioxide (TeO_2)....	White to pale yellow globules.
Selenium dioxide (SeO_2)......	White, crystalline, volatile.
Molybdenum trioxide (MoO_3)	Pale yellow, hot; white, cold.
Mercury (Hg).............	Gray metallic globules, easily united by rubbing.

It is also to be noted that if the heating process is too rapid for full oxidation, sublimates, like those of the closed tubes, may be formed, especially with sulphur (yellow), arsenic (black), arsenic sulphide (orange), mercury sulphide (black), antimony oxysulphide (black to reddish brown).

3. Heating on Charcoal

498. The fragment (or powder) to be examined is placed near one end of the piece and this so held that the flame passes along its length. If the mineral decrepitates, it may be powdered, mixed with water, and then the material employed as a paste.

The reducing flame is employed if it is desired to *reduce* a metal (*e.g.*, silver, copper) from its ores: this is the common case. If, however, the mineral is to be *roasted*, that is, heated in contact with the air so as to oxidize and volatilize, for example, the sulphur, arsenic, antimony present, the oxidizing flame is needed and the mineral should be in powder and spread out.

The points to be noted are as follows:

(*a*) The *odor* given off after short heating. In this way the presence of *sulphur*, *arsenic* (garlic or alliaceous odor), and *selenium* (odor of decayed horseradish) may be recognized.

(*b*) *Fusion.* — In the case of the salts of the alkalies the fused mass is absorbed into the charcoal; this is also true, after long heating, of the carbonates and sulphates of barium and strontium. (Art. **501.**)

(*c*) *The Sublimate.* — By this means the presence of many of the metals may be determined. The color of the sublimate, both near the assay (N) and at a distance (D), as also when hot and when cold, is to be noted.

The important sublimates are the following:

Substance	Sublimate on Charcoal
Arsenic trioxide (As_2O_3)	White, very volatile, distant from the assay; also garlic fumes.
Antimony oxides (Sb_2O_3 and Sb_2O_4)	Dense white, volatile; forms near the assay.
Zinc oxide (ZnO)	Canary-yellow, hot; white, cold; moistened with cobalt nitrate and ignited (O.F.) becomes green.
Molybdenum trioxide (MoO_3)	Pale yellow, hot; yellow, cold; touched for a moment with the R.F. becomes azure-blue. Also a copper-red sublimate (MoO_2) near the assay.
Lead oxide (PbO)	Dark yellow, hot; pale yellow, cold. Also (from sulphides) dense white (resembling antimony), a mixture of oxide, sulphite, and sulphate of lead.
Bismuth trioxide (Bi_2O_3)	Dark orange-yellow (N), paler on cooling; also bluish white (D). See further, p. 338.
Cadmium oxide (CdO)	Nearly black to reddish brown (N) and orange-yellow (D); often iridescent.

To the above are also to be added the following:

Selenium dioxide, SeO_2, sublimate steel-gray (N) to white tinged with red (D); touched with R.F. gives an azure-blue flame; also an offensive selenium odor.

Tellurium dioxide, TeO_2, sublimate dense white (N) to gray (D); in R.F. volatilizes with green flame.

Tin dioxide, SnO_2, sublimate faint yellow hot to white cold; becomes bluish green when moistened with cobalt solution and ignited.

Silver (with lead and antimony), sublimate reddish

(*d*) *The Infusible Residue.* — This may (1) glow brightly in the O.F., indicating the presence of calcium, strontium, magnesium, zirconium, zinc, or tin. (2) It may give an alkaline reaction after ignition: alkaline earths. (3) It may be magnetic, showing the presence of iron (or nickel). (4) It may yield a globule or mass of a metal (Art. **499**).

499. Reduction on Charcoal. — In many cases the reducing flame alone suffices on charcoal to separate the metal from the volatile element present, with the result of giving a globule or metallic mass. Thus silver is obtained from argentite (Ag_2S) and cerargyrite (AgCl); copper from chalcocite (Cu_2S) and cuprite (Cu_2O), etc. The process of reduction is always facilitated by the use of sodium carbonate or borax as a flux, and this is in many cases (sulpharsenites, etc.) essential.

The finely pulverized mineral is intimately mixed with two or three times its volume of soda, and a drop of water added to form a paste. This is placed in a cavity in the charcoal, and subjected to a strong reducing flame. More soda is added as that present sinks into the coal, and, after the process has been continued some time, a metallic globule is often visible, or a number of them, which can be removed and separately examined. If not distinct, the remainder of the flux, the assay, and the surrounding coal are cut out with a knife, and the whole ground up in a mortar, with the addition of a little water. The charcoal is carefully washed away and the metallic globules, flattened out by the process, remain behind. Some metallic oxides are very readily reduced, as lead, while others, as copper and tin, require considerable skill and care.

The metals obtained (in globules or as a metallic mass) may be: *copper*, color red; *bismuth*, lead-gray, brittle; *gold*, yellow, not soluble in nitric acid; *silver*, white, soluble in nitric acid, the solution giving a silver chloride precipitate (p. 340); *tin*, white, harder than silver, soluble in nitric acid with separation of white powder (SnO_2); *lead*, lead-gray (oxidizing), soft and fusible. The coatings (see the list of sublimates above) often serve to identify the metal present.

500. Detection of Sulphur in Sulphates. — By means of soda on charcoal the presence of sulphur in the sulphates may be shown, in the following manner. Fuse the powdered mineral with soda and charcoal dust. The latter acting as a strong reducing agent changes the sulphate to a sulphide with the formation of sodium sulphide. When the fused mass is placed with a drop of water upon a clean silver surface a black or yellow stain of silver sulphide will be formed. A similar reaction would of course be obtained from a sulphide. The latter can however be readily distinguished by roasting in the open tube or upon charcoal and noting the formation of SO_2.

4. TREATMENT ON THE PLATINUM WIRE

501. Use of the Fluxes. — The three common fluxes are borax, salt of phosphorus, and carbonate of soda (p. 330). They are generally used with the platinum wire, less often on charcoal (see p. 335). If the wire is employed it must have a small loop at the end; this is heated to redness and dipped into the powdered flux, and the adhering particles fused to a bead; this operation is repeated until the loop is filled. Sometimes in the use of soda the wire may at first be moistened a little to cause it to adhere.

When the bead is ready, it is, while hot, brought in contact with the powdered mineral, some of which will adhere to it, and then the heating process may be continued. Very little of the mineral is in general required, and the experiment should be commenced with a minute quantity and more added if necessary. The bead must be heated successively first in the oxidizing flame (O.F.) and then in the reducing flame (R.F.), and in each case the color noted when *hot* and when *cold*. The phenomena connected with fusion, if it takes place, must also be observed.

Minerals containing sulphur or arsenic, or both, must be first *roasted* (see p. 334) till these substances have been volatilized. If too much of the mineral has been added and the bead is hence too opaque to show the color, it may, while hot, be flattened out with the hammer, or drawn out into a wire, or part of it may be removed and the remainder diluted with more of the flux.

With salt of phosphorus, the wire should be held above the flame so that the escaping gases may support the bead; this is continued till quiet fusion is attained.

It is to be noted that the colors vary much with the amount of material present; they are also modified by the presence of other metals.

502. Borax. — The following list enumerates the different colored beads obtained with borax, both in the oxidizing (O.F.) and reducing flames (R.F.), and also the metals to the presence of whose oxides the colors are due. Compare further the reactions given in the list of elements (Art. **504**).

Color in Borax Bead	Substance
	1. OXIDIZING FLAME
Colorless, or opaque white...	Silica, calcium, aluminium; also silver, zinc, etc.
	Iron, cold — (pale yellow, hot, if in small amount).
Red, red-brown to brown....	Chromium (CrO_3), hot — (yellowish green, cold).
	Manganese (Mn_2O_3), amethystine-red — (violet, hot).
	Iron (Fe_2O_3), hot — (yellow, cold) — if saturated.
	Nickel (NiO) red-brown to brown, cold — (violet, hot).
	Uranium (UO_3), hot — (yellow, cold).
Green....................	Copper (CuO), hot — (blue, cold, or bluish green if highly saturated).
	Chromium (CrO_3), yellowish green, cold — (red, hot).

Yellow	Iron (Fe_2O_3), hot — (pale yellow to colorless, cold) — but red-brown and yellow if saturated.
	Uranium (UO_3), hot, if in small amount; paler on cooling.
	Chromium (CrO_3), hot and in small amount — (yellowish green, cold).
Blue	Cobalt (CoO), hot and cold.
	Copper (CuO), cold if highly saturated — (green, hot).
Violet	Nickel (NiO), hot — (red-brown, cold).
	Manganese (Mn_2O_3), hot — (amethystine-red, cold).

2. Reducing Flame (R.F.)

Colorless	Manganese (MnO), or a faint rose color.
Red	Copper (Cu_2O, with Cu), opaque red.
Green	Iron (FeO), bottle-green.
	Chromium (Cr_2O_3), emerald-green.
	Uranium (U_3O_8), yellowish green if saturated.
Blue	Cobalt (CoO), hot and cold.
Gray, turbid	Nickel (Ni).

503. Salt of Phosphorus. — This flux gives for the most part reactions similar to those obtained with borax. The only cases enumerated here are those which are distinct, and hence those where the flux is a good test.

With *silicates* this flux forms a glass in which the bases of the silicate are dissolved, but the silica itself is left insoluble. It appears as a skeleton readily seen floating about in the melted bead.

The colors of the beads, and the metals to whose oxides these are due, are:

Color	Substance
Red	Chromium in O.F., hot — (fine green when cold).
Green	Chromium in O.F. and R.F., when cold — (red in O.F., hot).
	Molybdenum in R.F., dirty green, hot; fine green, cold — (yellow-green in O.F.).
	Uranium in R.F., cold; yellow-green, hot.
	Vanadium, chrome-green in R.F., cold — (brownish red, hot). In O.F., dark yellow, hot, paler on cooling.
Yellow	Molybdenum, yellowish green in O.F., hot, paler on cooling — (in R.F., dirty green, hot; fine green, cold).
	Uranium in O.F., hot; yellowish green, cold — (in R.F., yellowish green, hot; green, cold).
	Vanadium in O.F., dark yellow, hot, paler on cooling — (in R.F., brownish red, hot; chrome-green, cold).
Violet	Titanium (TiO_2) in R.F., yellow, hot. (Also in O.F., yellow, hot; colorless, cold.)

CHARACTERISTIC REACTIONS OF THE IMPORTANT ELEMENTS AND OF SOME OF THEIR COMPOUNDS

504. The following list contains the most characteristic reactions, chiefly before the blowpipe and in some cases also in the wet way, of the different elements and their oxides. It is desirable for every student to gain familiarity with them by trial with as many minerals as possible. Many of them have already been briefly mentioned in the preceding pages. For a thoroughly full description of these and other characteristic tests (blowpipe and otherwise) reference should be made to the volume by Brush and Penfield referred to on p. 329.

It is to be remembered that while the reaction of a single substance may be perfectly distinct if alone, the presence of other substances may more or less entirely obscure these reactions; it is consequently obvious that in the actual examination of minerals precautions have to be taken, and special methods have to be devised, to overcome the difficulty arising from this cause. These will be gathered from the "pyrognostic characters" (Pyr.) given in connection with the description of each species in the Fourth Part of this work.

Aluminium. — The presence of aluminium in most infusible minerals, containing a considerable amount, may be detected by the blue color which they assume when, after being heated, they are moistened with cobalt solution and again ignited (*e.g.*, cyanite, andalusite, etc.). Very hard minerals (as corundum) must be first finely pulverized. The test is not conclusive with fusible minerals since a glass colored blue by cobalt oxide may be formed. It is to be noted that the infusible calamine (zinc silicate) also assumes a blue color when treated with cobalt nitrate. From solutions aluminium will be precipitated as a flocculent white or colorless precipitate on the addition of ammonium hydroxide in excess.

Antimony. — Antimonial minerals roasted on charcoal give dense white odorless fumes; metallic antimony and its sulphur compounds give in the open tube a white sublimate of oxide of antimony (see p. 334). Antimony sulphide (stibnite), also many sulphantimonites, give in a strong heat in the closed tube a sublimate of antimony oxysulphide, black when hot, brown-red when cold. See also p. 333.

In nitric acid, compounds containing antimony deposit white insoluble metantimonic acid.

Arsenic. — Arsenides, sulpharsenites, etc., give off fumes when roasted on charcoal, usually easily recognized by their peculiar garlic odor. In the open tube they give a white, volatile, crystalline sublimate of arsenic trioxide. In the closed tube arsenic sulphide gives a sublimate dark brown-red when hot, and red or reddish yellow when cold; arsenic and some arsenides yield a black mirror of metallic arsenic in the closed tube. In arsenates the arsenic can be detected by the garlic odor yielded when a mixture of the powdered mineral with charcoal dust and sodium carbonate is heated (R.F.) on charcoal.

Barium. — A yellowish green coloration of the flame is given by all barium salts, except the silicates; an alkaline reaction is usually obtained after intense ignition.

In solution the presence of barium is proved by the heavy white precipitate ($BaSO_4$) formed upon the addition of dilute sulphuric acid.

Bismuth. — On charcoal alone, or better with soda, bismuth gives a very characteristic orange-yellow sublimate; brittle globules of the reduced metal are also obtained (with soda). Also when treated with 3 or 4 times the volume of a mixture in equal parts of potassium iodide and sulphur, and fused on charcoal, a beautiful red sublimate of bismuth iodide is obtained; near the mineral the coating is yellow.

Boron. — Many compounds containing boron (borates, also the silicates, datolite, danburite, etc.) tinge the flame intense yellowish green, especially if moistened with sulphuric acid. For some silicates (as tourmaline) the best method is to mix the powdered mineral with one part powdered fluorite and two parts potassium bisulphate. The mixture is moistened and placed on platinum wire. At the moment of fusion the green color appears, but lasts but an instant.

A dilute hydrochloric acid solution containing boron gives a reddish brown color to turmeric paper which has been moistened with it and then dried at 100°; the color changes to black when ammonia is poured on the paper.

Calcium. — Many calcium minerals (carbonates, sulphates, etc.) give an alkaline reaction on turmeric paper after being ignited. A yellowish red color is given to the flame by some compounds (*e.g.*, calcite after moistening with HCl); the strontium flame is a much deeper red.

In weakly acid or alkaline solutions calcium is precipitated as oxalate by the addition of ammonium oxalate.

Cadmium. — On charcoal with soda, compounds of cadmium give a characteristic sublimate of the reddish brown oxide.

Carbonates. — All carbonates effervesce with *dilute* hydrochloric acid, yielding the odorless gas CO_2 (*e.g.*, calcite); many require to be pulverized, and some need the addition of heat (dolomite, siderite). Carbonates of lead should be tested with nitric acid.

Chlorides. — If a small portion of a mineral containing chlorine (a chloride, also pyromorphite, etc.) is added to the bead of salt of phosphorus, saturated with copper oxide, the bead when heated is instantly surrounded with an intense purplish flame of copper chloride.

In solution chlorine gives with silver nitrate a white curdy precipitate of silver chloride which darkens in color on exposure to the light; it is insoluble in nitric acid, but entirely soluble in ammonia.

Chromium. — Chromium gives with borax a bead which (O.F.) is yellow to red (hot) and yellowish green (cold) and R.F. a fine emerald-green. With salt of phosphorus in O.F. the bead is dirty green (hot) and clear green (cold); in R.F. the same. Cf. Vanadium beyond (also pp. 336, 337).

Cobalt. — A beautiful blue bead is obtained with borax in both flames from minerals containing cobalt. Where sulphur or arsenic is present the mineral should first be thoroughly roasted on charcoal.

Copper. — On charcoal, at least with soda, metallic copper can be reduced from most of its compounds. In the case of sulphides the powdered mineral should be roasted first in order to eliminate the major part of the sulphur before fusion with soda. With borax it gives (O.F.) a green bead when hot, becoming blue when cold; also (R.F.), if saturated, an opaque red bead containing Cu_2O and often Cu is obtained. Copper chloride, obtained by moistening the mineral with hydrochloric acid (in the case of sulphides the mineral should be previously roasted) yields a vivid azure-blue flame; copper oxide gives a green flame.

Most metallic compounds are soluble in nitric acid. Ammonia in excess produces an intense blue color in the solution.

Fluorine. — Heated in the closed tube with potassium bisulphate and powdered glass produces a white sublimate of SiO_2. This sublimate and the hydrofluosilicic acid present form a volatile combination. But if the lower end of the tube is broken off and the open tube then dipped in a test tube of water so that the acid is removed, the deposit of SiO_2 which will appear when the tube is dried will be found to be no longer volatile.

Heated gently in a platinum crucible with sulphuric acid, many compounds (*e.g.*, fluorite) give off hydrofluoric acid, which corrodes the exposed parts of a glass plate placed over it which has been coated with wax and then scratched.

Iron. — Minerals which contain even a small amount of iron yield a magnetic mass when heated in the reducing flame. With borax iron gives a bead (O.F.) which is yellow to brownish red (according to quantity) while hot, but is colorless to yellow on cooling; R.F. becomes bottle-green (see pp. 336, 337).

Lead. — With soda on charcoal a malleable globule of metallic lead is obtained from lead compounds; the coating has a yellow color near the assay; the sulphide gives also a white coating ($PbSO_4$) farther off (p. 335). On being touched with the reducing flame the coating disappears, tingeing the flame azure-blue.

In solutions dilute sulphuric acid gives a white precipitate of lead sulphate; when delicacy is required an excess of the acid is added, the solution evaporated to dryness, and water added; the lead sulphate, if present, will then be left as a residue.

Lithium. — Lithium gives an intense carmine-red to the outer flame, the color somewhat resembling that of the strontium flame but is deeper; in very small quantities it is evident in the spectroscope.

Magnesium. — Moistened, after heating, with cobalt nitrate and again ignited, a pink color is obtained from some infusible compounds of magnesium (*e.g.*, brucite). In solution the addition of ammonium hydroxide in large excess and a little hydrogen sodium phosphate produces a white granular precipitate of NH_4MgPO_4. Elements precipitated by ammonium hydroxide or ammonium oxalate should be removed first.

Manganese. — With borax manganese gives a bead violet-red (O.F.), and colorless (R.F.). With soda (O.F.) it gives a bluish green bead; this reaction is very delicate and may be relied upon, even in presence of almost any other metal.

Mercury. — In the closed tube a sublimate of metallic mercury is yielded when the mineral is heated with dry sodium carbonate. In the open tube the sulphide gives a mirror of metallic mercury; in the closed tube a black lusterless sublimate of HgS, red when rubbed, is obtained.

Molybdenum. — On charcoal molybdenum sulphide gives near the assay a copper-red stain (O.F.), and beyond a white coating of the oxide; the former becomes azure-blue when for a moment touched with the R.F. The salt of phosphorus bead (O.F.) is yellowish green (hot) and nearly colorless (cold); also (R.F.) a fine green.

Nickel. — With borax, nickel oxide gives a bead which (O.F.) is violet when hot and red-brown on cooling; (R.F.) the glass becomes gray and turbid from the separation of metallic nickel.

Niobium (Columbium). — An acid solution boiled with metallic tin gives a blue color. The reactions with the fluxes are not very satisfactory.

Nitrates. — These detonate when heated on charcoal. Heated in a tube with sulphuric acid they give off red fumes of nitrogen dioxide (NO_2).

Phosphorus. — Most phosphates impart a green color to the flame, especially after having been moistened with sulphuric acid, though this test may be rendered unsatisfactory by the presence of other coloring agents. If they are used in the closed tube with a fragment of metallic magnesium or sodium, and afterward moistened with water, phosphureted hydrogen is given off, recognizable by its disagreeable odor.

A few drops of a nitric acid solution, containing phosphoric acid, produce in a solution of ammonium molybdate a pulverulent yellow precipitate of ammonium phosphomolybdate.

Potassium. — Potash imparts a violet color to the flame when alone. The flame is best observed through a blue glass filter which will eliminate the sodium flame color which will almost invariably be present. It is best detected in small quantities, or when soda or lithia is present, by the aid of the spectroscope. See also p. 333.

Selenium. — On charcoal selenium fuses easily, giving off brown fumes with a peculiar disagreeable organic odor; the sublimate on charcoal is volatile, and when heated (R.F.) gives a fine azure-blue flame.

Silicon. — A small fragment of a silicate in the salt of phosphorus bead leaves a skeleton of silica, the bases being dissolved.

If a silicate in a fine powder is fused with sodium carbonate and the mass then dissolved in hydrochloric acid and evaporated to dryness, the silica separates as a gelatinous mass and on evaporation to dryness is made insoluble. When strong hydrochloric acid is added and then water to the dry residue in the test tube, the bases are dissolved and the silica left behind.

Many silicates, especially those which are hydrous, are decomposed by strong hydrochloric acid, the silica separating as a powder or, after evaporation, as a jelly (see p. 328).

Silver. — On charcoal in O.F. silver gives a brown coating. A globule of metallic silver may generally be obtained by heating on charcoal in O.F., especially if soda is added. Under some circumstances it is desirable to have recourse to cupellation.

From a solution containing any salt of silver, the insoluble chloride is thrown down when hydrochloric acid is added. This precipitate is insoluble in acid or water, but entirely so in ammonia. It changes color on exposure to the light.

Strontium. — Compounds of strontium are usually recognized by the fine crimson-red which they give to the blowpipe flame; many yield an alkaline reaction after ignition. (Cf. barium.)

Sodium. — Compounds containing sodium in large amount give a strong yellow flame.

Sulphur, Sulphides, Sulphates. — In the closed tube some sulphides give off sulphur; in the open tube they yield sulphur dioxide, which has a characteristic odor and reddens a strip of moistened litmus paper. In small quantities, or in sulphates, sulphur is best detected by fusion on charcoal with soda and charcoal dust. The fused mass, when sodium sulphide has thus been formed, is placed on a clean silver coin and moistened; a distinct black stain on the silver is thus obtained (the precaution mentioned on p. 336 must be exercised).

A solution of a sulphate in hydrochloric acid gives with barium chloride a white insoluble precipitate of barium sulphate.

Tellurium. — Tellurides heated in the open tube give a white or grayish sublimate, fusible to colorless drops (p. 334). On charcoal they give a white coating and color the R.F. green.

Tin. — Minerals containing tin (*e.g.*, cassiterite), when heated on charcoal with soda or potassium cyanide, yield metallic tin in minute globules; these are malleable, but harder than silver. Dissolved in nitric acid, white insoluble stannic oxide separates out.

Titanium. — Titanium gives in the R.F. with salt of phosphorus a bead which is violet when cold. Fused with sodium carbonate and dissolved with hydrochloric acid, and heated with a piece of metallic tin, the liquid takes a violet color, especially after partial evaporation.

Tungsten. — Tungsten oxide gives a blue color to the salt of phosphorus bead (R.F.). Fused and treated as titanium (see above) with the addition of zinc instead of tin, gives a fine blue color.

Uranium. — Uranium compounds give to the salt of phosphorus bead (O.F.) a greenish yellow bead when cool; also (R.F.) a fine green on cooling (p. 337).

Vanadium. — With borax (O.F.) vanadates give a bead yellow (hot) changing to yellowish green and nearly colorless (cold); also (R.F.) dirty green (hot), fine green (cold). With salt of phosphorus (O.F.) a yellow to amber color (thus differing from chromium); also (R.F.) fine green (cold).

Zinc. — On charcoal in the reducing flame compounds of zinc give a coating which is yellow while hot and white on cooling, and moistened by the cobalt solution and again heated becomes a fine green. Note, however, that the zinc silicate (calamine) becomes blue when heated after moistening with cobalt solution.

Zirconium. — A dilute hydrochloric acid solution, containing zirconium, imparts an orange-yellow color to turmeric paper, moistened by the solution.

DETERMINATIVE MINERALOGY

505. Determinative Mineralogy may be properly considered under the general head of Chemical Mineralogy, since the determination of minerals depends mostly upon chemical tests. But crystallographic and all the physical characters have also to be carefully observed.

There is but one exhaustive way in which the identity of an unknown mineral may in all cases be fixed beyond question, and that is by the use of a complete set of determinative tables. By means of such tables the mineral in hand is referred successively from a general group into a more special one, until at last all other species have been eliminated, and the identity of the one given is beyond doubt.

A careful preliminary examination of the unknown mineral should, however, always be made before final recourse is had to the tables. This examination will often suffice to show what the mineral in hand is, and in any case it should not be omitted, since it is only in this way that a practical familiarity with the appearance and characters of minerals can be gained.

The student will naturally take note first of those characters which are at once obvious to the senses, that is: *crystalline form*, if distinct; *general structure, cleavage, fracture, luster, color* (and *streak*), *feel;* also, if the specimen is not too small, the apparent weight will suggest something as to the *specific gravity*. The characters named are of very unequal importance. Structure, if crystals are not present, and fracture are generally unessential except in distinguishing varieties; color and luster are essential with metallic, but generally very unimportant with nonmetallic, minerals. *Streak* is of importance only with colored minerals and those of metallic luster (p. 247). Crystalline form and cleavage are of the highest importance, but may require careful study.

The first trial should be the determination of the *hardness* (for which end the pocket-knife is often sufficient in experienced hands). The second trial should be the determination of the *specific gravity*. Treatment of the powdered mineral with acids may come next; by this means (see pp. 328, 329) a carbonate is readily identified, and also other results obtained. Then should follow blowpipe trials, to ascertain the *fusibility;* the *color* given to the flame, if any; the character of the *sublimate* given off in the tubes and on charcoal; the metal reduced on the latter; the reactions with the *fluxes*, and other points as explained in the preceding pages.

How much the observer learns in the above way, in regard to the nature of his mineral, depends upon his knowledge of the characters of minerals in general, and upon his familiarity with the chemical behavior of the various elementary substances with reagents and before the blowpipe (pp. 338 to 341). If the results of such a preliminary examination are sufficiently definite to suggest that the mineral in hand is one of a small number of species, reference may be made to their full description in Part. IV of this work for the final decision.

A number of tables, in which the minerals included are arranged according to their crystalline and physical characters, are added in the Appendix. They will in many cases aid the observer in reaching a conclusion in regard to a specimen in hand.

The first of these tables gives lists of minerals arranged primarily according to their principle basic elements and secondarily according to their acid radicals.

The second of these tables is intended to include all well-defined species, grouped according to the crystalline system to which they belong and arranged under each system in the order of their specific gravities; the hardness is also added in each case. The relative importance of the individual species is shown by the type employed. Following this are minor tables enumerating species characterized by some one of the prominent crystalline forms; that is, those crystallizing in cubes, octahedrons, rhombohedrons, etc. Other tables give the names of species prominent because of their cleavage; structure of different types; hardness; luster; the various colors, etc. The student is recommended to make frequent use of these tables, not simply for aid in the identification of specimens, but rather because they will help him in the difficult task of learning the prominent characters of the more important minerals.

PART IV. DESCRIPTIVE MINERALOGY

506. Scope of Descriptive Mineralogy. — It is the province of Descriptive Mineralogy to describe each mineral species, as regards: (1) form and structure; (2) physical characters; (3) chemical composition including blowpipe and chemical tests; (4) occurrence in nature with reference to geographical distribution and association with other species; also in connection with the above to show how it may be distinguished from other species. Further, it should classify mineral species into more or less comprehensive groups according to those characters regarded as most essential. Other points which may or may not be included are the investigation of the methods of origin of minerals; the changes that they undergo in nature and the results of such alteration; also the methods by which the same compounds may be made in the laboratory; finally, the uses of minerals as ores, for ornament and in the arts.

507. Scheme of Classification. — The method of classification adopted in this work, and the one which can alone claim to be thoroughly scientific, is that which places similar chemical compounds together in a common class and which further arranges the mineral species into groups according to the more minute relations existing between them in chemical composition, crystalline form and other physical properties.

Upon this basis there are recognized eight distinct chemical classes, beginning with the Native Elements; these are enumerated on the following page. Under each of these, sections of different grades are made, also based on chemical relationships. Finally, the mineral species themselves are arranged, as far as possible, in isomorphous groups, including those which have, at once, analogous chemical composition and similar crystallization (see Art. **471**). It is unnecessary to take the space here to develop the entire scheme of classification in detail, since a survey of the successive sub-classes under any one of the divisions will make the principles followed entirely clear. A few remarks, only, are added for sake of illustration.

Under the Oxides, for example, the classification is as follows: First, the Oxides of silicon (quartz, tridymite, opal). Second, the Oxides of the semimetals, tellurium, arsenic, antimony, bismuth, also molybdenum, tungsten. Third, the Oxides of the metals, as copper, zinc, iron, manganese, tin, etc. The third section is then subdivided into the anhydrous and hydrous species. Further, the former fall into the four divisions: Protoxides, R_2O and RO; Sesquioxides, R_2O_3; Intermediate oxides, RO,R_2O_3; Dioxides, RO_2. Under each of these heads come finally the individual species, arranged so far as possible in isomorphous groups. Thus we have the Hematite group, the Rutile group, etc.

In regard to the various classes of salts it may be stated that, in general, they are separated into anhydrous, acid, basic and hydrous sections; the special subdivisions called for, however, vary in the different cases.

For an explanation of the abbreviations used in the description of species, see p. 5.

SCHEME OF CLASSIFICATION

I. **NATIVE ELEMENTS.**

II. **SULPHIDES, SELENIDES, TELLURIDES, ARSENIDES, ANTIMONIDES.**

III. *Sulpho-salts.* — **SULPHARSENITES, SULPHANTIMONITES, SULPHOBISMUTHITES.**

IV. *Haloids.* — **CHLORIDES, BROMIDES, IODIDES; FLUORIDES.**

V. **OXIDES.**

VI. *Oxygen Salts.*

   1. **CARBONATES.**
   2. **SILICATES, TITANATES.**
   3. **NIOBATES, TANTALATES.**
   4. **PHOSPHATES, ARSENATES, VANADATES; ANTIMONATES. NITRATES.**
   5. **BORATES. URANATES.**
   6. **SULPHATES, CHROMATES, TELLURATES.**
   7. **TUNGSTATES, MOLYBDATES.**

VII. *Salts of Organic Acids:* Oxalates, Mellates, etc.

VIII. **HYDROCARBON COMPOUNDS.**

I. NATIVE ELEMENTS

The NATIVE ELEMENTS are divided into the two distinct sections of the Metals and the Non-metals, and these are connected by the transition class of the Semi-metals. The distinction between them as regards physical characters and chemical relations has already been given (Art. **453**).

The only *non-metals* present among minerals are carbon, sulphur, and selenium; the last, in one of its allotropic forms, is closely related to the semi-metal tellurium.

The native *semi-metals* form a distinct group by themselves, since all crystallize in the rhombohedral class of the hexagonal system with a fundamental angle differing only a few degrees from 90°, as shown in the following list:

Tellurium, $rr' = 93°\ 3'$. Arsenic, $rr' = 94°\ 54'$.
Antimony, $rr' = 92°\ 53'$. Bismuth, $rr' = 92°\ 20'$.

An artificial form of selenium is known with metallic luster and rhombohedral in crystallization, with $rr' = 93°$. Zinc (also only artif.) is rhombohedral ($rr' = 93°\ 46'$) and connects the semi-metals to the true metals. Metallic tantalum has been described in cubic crystals.

Among the *metals* the isometric GOLD GROUP is prominent, including gold, silver, copper, mercury, amalgam (AgHg), and lead.

Another related isometric group includes the metals platinum, iridium, palladium, and iron. An allotropic form of palladium and also iridosmine (IrOs) are both rhombohedral.

DIAMOND.

Isometric, tetrahedral, but with the + and − forms usually equally developed and not to be distinguished from each other. Commonly showing octahedral, hexoctahedral, and other forms; faces frequently rounded or striated and with triangular depressions (on *o*(111)). Twins common with tw. pl. *o*(111). Crystals often distorted. In spherical forms; massive.

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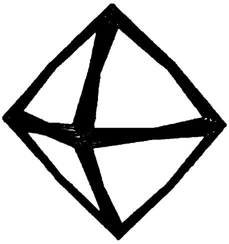

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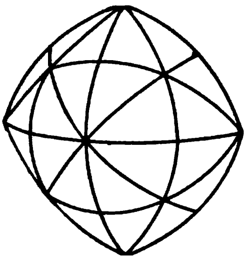

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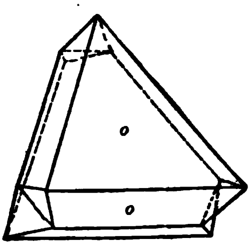

Cleavage: *o*(111) highly perfect. Fracture conchoidal. Brittle. H. = 10. G. = 3·516–3·525 crystals. Luster adamantine to greasy. Color white or colorless; occasionally various pale shades of yellow, red, orange, green, blue, brown; rarely deeply colored; sometimes black. Usually transparent; also translucent, opaque. Refractive and dispersive power high; index $n = 2{\cdot}4195$. (See Art. **328.**)

Var. — 1. *Ordinary.* In crystals usually with rounded faces and varying from those which are colorless and free from flaws (*first water*) through many faint shades of color, yellow being the most common; often full of flaws and hence of value only for cutting purposes.

2. *Bort* or *Boort;* rounded forms with rough exterior and radiated or confused crystalline structure.

3. *Carbonado* or *Carbon;* black diamond. Massive, crystalline, granular to compact, without cleavage. Color black or grayish black. Opaque. Obtained chiefly from Bahia, Brazil.

Comp. — Pure carbon; the variety carbonado yields on combustion a slight ash.

Pyr., etc. — Unaffected by heat except at very high temperatures, when (in an oxygen atmosphere) it burns to carbon dioxide (CO_2); out of contact with the air transformed into a kind of coke. Not acted upon by acids or alkalies.

Diff. — Distinguished (*e.g.*, from quartz crystal) by its extreme hardness and brilliant adamantine luster; the form, cleavage, and high specific gravity are also distinctive characters; it is optically isotropic; transparent to X-rays.

Artif. — Minute diamonds have been formed artificially in several ways. Moissan first produced them by dissolving carbon in molten iron and then cooling the mass suddenly under pressure; they have been formed by dissolving graphite in fused olivine or artificial magnesium silicate melts; they have been formed when an electric current was passed through an iron spiral embedded in carbon while under high pressure in an atmosphere of hydrogen.

Obs. — The diamond occurs chiefly in alluvial deposits of gravel, sand, or clay, associated with quartz, gold, platinum, zircon, octahedrite, rutile, brookite, hematite, ilmenite, and also andalusite, chrysoberyl, topaz, corundum, tourmaline, garnet, etc.; the associated minerals being those common in granitic rocks or granitic veins. Also found in quartzose conglomerates, and further in connection with the laminated granular quartz rock or quartzose hydromica schist, *itacolumite*, which in thin slabs is more or less flexible. This rock occurs at the mines of Brazil and the Ural Mts.; and also in Georgia and North Carolina, where a few diamonds have been found.

It has been reported as occurring *in situ* in a pegmatite vein in gneiss at Bellary in India. It occurs further in connection with an eruptive peridotite in South Africa and in a similar formation in Pike County, Ark. It has been noted as grayish particles forming one per cent of the meteorite which fell at Novo-Urei, Russia, Sept. 22, 1886; also in the form of black diamond (H. = 9) in the meteorite of Carcote, Chile; in the meteoric iron of Cañon Diablo, Ariz.

India was the chief source of diamonds from very early times down to the discovery of the Brazilian mines; the yield is now small. Of the localities, that in southern India, in the Madras presidency, included the famous "Golconda mines." The diamond deposits of Brazil have been worked since the early part of the 18th century, and have yielded very largely, although at the present time the amount obtained is small. The most important region was that near Diamantina in the province of Minas Geraes; also from Bahia, etc.

The discovery of diamonds in South Africa dates from 1867. They were first found in the gravel of the Vaal river; they occur from Potchefstroom down to the junction with the Orange river, and along the latter as far as Hope Town. More recently they have been found in gravels in the Somabula Forest, Rhodesia and at Lüderitzbucht, German South West Africa. These *river diggings* are now of much less importance than the *dry diggings*, discovered in 1871.

The latter are chiefly in Griqualand-West, south of the Vaal river, on the border of the Orange Free State. There are here near Kimberley a number of limited areas approximately spherical or oval in form, with an average diameter of some 200 to 300 yards, of which the Kimberley, De Beer's, Dutoitspan and Bultfontein mines are the most important. A circle 3½ miles in diameter encloses these four principal mines. The general structure is similar: a wall of nearly horizontal black carbonaceous shale with upturned edges enclosing the diamantiferous area. The upper portion of the deposit consists of a friable mass of little coherence of a pale yellow color, called the "yellow ground." Below the reach of atmospheric influences, the rock is more firm and of a bluish green or greenish color; it is called the "blue ground" or simply "the blue." This consists essentially of a serpentinous breccia: a base of hydrated magnesian silicate penetrated by calcite and opaline silica and enclosing fragments of bronzite, diallage, also garnet, magnetite, and ilmenite, and less commonly smaragdite, pyrite, zircon, etc. The diamonds are rather abundantly disseminated through the mass, in some claims to the amount of 4 to 6 carats per cubic yard. The original rock seems to have been a peculiar type of peridotite. These areas are believed to be volcanic pipes, and the occurrence of the diamonds is obviously connected with the eruptive outflow, they having probably been brought up from underlying rocks. Other important mines, similar in character to those near Kimberley, are the Jagersfontein mine in Orange Free State and the Premier, near Pretoria, Transvaal.

The South African mines up to the beginning of 1914 are estimated to have yielded about 120 million carats (26 tons) of diamonds valued at nearly 900 million dollars.

Diamonds are also obtained in Borneo, associated with platinum, etc.; in Australia, and the Ural Mts.

In the United States a few stones have been found in gravels in N. C., Ga., Va., Col., Cal. and Wis. Reported from Idaho and from Oregon with platinum. In 1906 diamonds were found in Pike County, Ark., both loose in the soil and enclosed in a peridotite rock. Considerable exploration work has been done at this locality and probably between two and three thousand stones found. The stones have been of good color but usually small.

Some of the famous diamonds of the world with their weights are as follows: the Kohinoor, which weighed when brought to England 186 carats, and as recut as a brilliant, 106 carats; the Orloff, 194 carats; the Regent or Pitt, 137 carats; the Florentine or Grand Duke of Tuscany, 133 carats. The "Star of the South" found in Brazil weighed before and after cutting respectively 254 and 125 carats. Also famous because of the rarity of their color are the green diamond of Dresden, 40 carats, and the deep blue Hope diamond from India, weighing 44 carats.

South Africa has yielded some very large stones. Among these may be mentioned the following: From the Jagersfontein mine the Excelsior weighing 969 carats; the Jubilee, 634 carats; and the Imperial, 457 carats. The largest diamond known was found in 1905 at the Premier mine. It was named the Cullinan and was presented by the Transvaal Assembly to King Edward VII of England. When found it weighed 3,025 carats or over 1⅓ lbs. It has since been cut into 105 separate stones, the two largest weighing 516 and 309 carats, respectively, being the largest cut stones in existence. The history of the above stones and of others is given in many works on gems.

Use. — In addition to its use as a gem, the diamond is extensively used as an abrasive. Crystal fragments are used to cut glass. The fine powder is employed in grinding and polishing gem stones. The noncrystalline, opaque varieties, especially the carbonado, are used in the bits of diamond drills. The diamond is also used in wire drawing and in the making of tungsten filaments for electric lights.

CLIFTONITE. — Carbon in minute cubic and cubo-octahedral crystals. H. = 2·5. G. = 2·12. Color and streak black; from the Youndegin, West Australia, meteoric iron, found in 1884, and other meteoric irons.

GRAPHITE. Plumbago. Black Lead.

Rhombohedral. In six-sided tabular crystals. Commonly in embedded foliated masses, also columnar or radiated; scaly or slaty; granular to compact; earthy.

Cleavage: basal, perfect. Thin laminæ flexible, inelastic. Feel greasy. H. = 1–2. G. = 2·09–2·23. Luster metallic, sometimes dull, earthy. Color iron-black to dark steel-gray. Opaque. A conductor of electricity.

Comp. — Carbon, like the diamond; often impure from the presence of ferric oxide, clay, etc.

Pyr., etc. At a high temperature some graphite burns more easily than diamond, other varieties less so. B.B. infusible. Unaltered by acids.

Diff. — Characterized by its extreme softness (soapy feel); iron-black color; metallic luster; low specific gravity; also by infusibility. Cf. molybdenite, p. 360.

Artif. — It is a common furnace product being formed from the fuel. It is produced extensively by heating coke in the electric furnace.

Obs. — Graphite is most commonly formed through the metamorphism of carbonaceous deposits and is most frequently found in metamorphic rocks, contact metamorphic deposits, etc. Coal beds may be largely converted into graphite by intense metamorphism It is not always of organic origin, however, as is shown by its occurrence in meteorites, in pegmatite deposits and as a magmatic separation in various igneous rocks. Frequently its origin is obscure. Found as beds and embedded masses, as laminæ or scales in granite, gneiss, mica schist, quartzite, crystalline limestone. The deposits of crystalline graphite which are of the greatest commercial importance have formed as veins along rock fractures.

Important localities are: Island of Ceylon from which the largest part of the world's supply comes; Passau district in Bavaria; southern Bohemia; Korea; Madagascar; Sonora in Mexico; eastern Ontario and adjacent portions of Quebec in Canada. The most productive locality in the United States is in the eastern and southeastern Adirondack region in Essex, Warren, Saratoga and Washington Counties, N. Y. It occurs here in graphitic quartzites, with quartz in small veins running through gneiss and in pegmatite veins. Also found in metamorphosed Carboniferous rocks near Providence and Tiverton, R. I.; in granite and schists in Clay, Chilton and Coosa Counties, Ala.; as amorphous graphite near Raton, N. M.; in irregular veins near Dillon, Mon.; near Turret, Chaffee Co., Col.

Use. — Its chief uses are for making crucibles and other refractory products, in lubricants, paint, stove polish, "lead" pencils and for foundry facings.

The name *black lead*, applied to this species, is inappropriate, as it contains no lead. The name graphite, of Werner, is derived from *γράφειν, to write*, alluding to its use for pencils.

QUISQUEITE. — A black lustrous material composed chiefly of carbon and sulphur from the vanadium ores of Minasragra, Peru.

SULPHUR.

Orthorhombic. Axes $a : b : c = 0·8131 : 1 : 1·9034$.

Crystals commonly acute pyramidal; sometimes thick tabular || $c(001)$. See also Fig. 79, p. 47. Also massive, in reniform shapes, incrusting, stalactitic and stalagmitic; in powder.

Cleavage: $c(001)$, $m(110)$, $p(111)$ imperfect. Fracture conchoidal to uneven. Rather brittle to imperfectly sectile. H. = 1·5–2·5. G. = 2·05–

2·09. Luster resinous. Color sulphur-yellow, straw- and honey-yellow, yellowish brown, greenish, reddish to yellowish gray. Streak white. Transparent to translucent. A non-conductor of electricity; by friction negatively electrified. A poor conductor of heat. Optically +. Double refraction strong. Ax. plane $\|\, b(010)$. Bx $\perp$ $c(001)$. Dispersion $\rho < v$. $2V = 69°5'$. Refractive indices, $\alpha = 1{\cdot}958$, $\beta = 2{\cdot}038$, $\gamma = 2{\cdot}245$.

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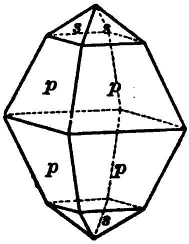

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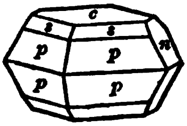

Comp. — Pure sulphur; often contaminated with clay, bitumen, and other impurities.

Sulphur may also be obtained in the laboratory in other allotropic forms; a monoclinic form is common.

Pyr., etc. — Melts at 108° C., and at 270° burns with a bluish flame yielding sulphur dioxide. Insoluble in water, and not acted on by the acids, but soluble in carbon disulphide.

Diff. — Readily distinguished by the color, fusibility and combustibility.

Obs. — The great repositories of sulphur are either beds of gypsum and the associate rocks, or the regions of active and extinct volcanoes.

Sulphur may have several different modes of origin. At times it is a volcanic sublimate formed by reactions between sulphur dioxide and hydrogen sulphide gases. It occurs frequently around mineral springs where it has been formed by the incomplete oxidation of hydrogen sulphide. Where such waters act upon limestone rocks both gypsum and sulphur may be formed. In a small way it is formed in many coal deposits and elsewhere by the slow decomposition of pyrite and other sulphides.

Found in large amounts on the Island of Sicily, often in fine crystals and associated with celestite, calcite, aragonite, gypsum, and barite. Important deposits are found in the volcanic districts of Japan, Hawaii, Mexico, and western South America. In the United States the most productive deposits are in Louisiana and Texas. In Calcasieu Parish, Louisiana, a bed of sulphur 100 ft. in thickness is found at a depth of between 300 and 400 ft. It is underlain by beds of gypsum and salt. A similar deposit occurs near Freeport in Brazoria Co., Texas. It is found in numerous other western localities; Utah, at Sulphurdale, Beaver Co., in a rhyolitic tuff; Wy., in limestones near Cody and Thermopolis and about the fumeroles of the Yellowstone Park; Nev., in Esmeralda Co. near Luning and Cuprite, near Rosebud, Humbolt Co., sometimes in crystals and at Eureka, Eureka Co.; Cal., in Colusa, Lake, San Bernadino and other Counties, at the geysers of Napa Valley, Sonoma Co., on Lassen Peak, Tehema Co.; Col., at Vulcan, Gunnison Co., and in Mineral Co.

Use. — In manufacture of sulphuric acid, in the process of making paper from wood pulp, in making matches, gun powder, fireworks, insecticides, for vulcanizing rubber, for medicinal purposes, etc. Sulphuric acid is now largely derived from the oxidation of pyrite.

Selensulphur. — Contains sulphur and selenium, orange-red or reddish brown; from the islands Vulcano and Lipari.

ARSENIC.

Rhombohedral. Generally granular massive; sometimes reticulated, reniform, stalactitic.

Cleavage: $c(0001)$ highly perfect. Fracture uneven and fine granular. Brittle. H. = 3·5. G. = 5·63–5·73. Luster nearly metallic. Color and streak tin-white, tarnishing to dark gray.

Comp. — Arsenic, often with some antimony, and traces of iron, silver, gold, or bismuth.

Pyr. — B.B. on charcoal volatilizes without fusing, coats the coal with white arsenic trioxide, and affords a garlic odor; the coating treated in R.F. volatilizes, tingeing the flame blue. In the closed tube gives a volatile sublimate of arsenic.

Micro. — In polished section shows white color similar to galena. Smooth surface. With HNO_3 slowly effervesces, turning dark. Changes color in same way with $FeCl_3$. Unaffected by KCN and HCl.

Obs. — Occurs in veins in crystalline rocks and the older schists, often accompanied by ores of antimony, the ruby silvers, realgar, sphalerite, and other metallic minerals. Thus in the silver mines of Saxony; also Andreasberg, Harz Mts., Germany; Joachimstal and Přibram, Bohemia; in Hungary; Norway; Zmeov, Siberia; Prov. Echizen, Japan, etc. Abundant at Chañarcillo, Chile. In the United States sparingly at Haverhill and Jackson, N. H.; near Leadville, Col.; Washington Camp, Santa Cruz Co., Ariz. In Canada at Watson Creek, British Columbia; Montreal, Quebec.

Use. — An ore of arsenic.

Allemontite. — Arsenical Antimony, $SbAs_3$. In reniform masses. G. = 6·203. Luster metallic. Color tin-white or reddish gray. From Allemont, France; Přibram, Bohemia, etc.

Tellurium. Rhombohedral. In prismatic crystals; commonly columnar to fine-granular massive. Perfect prismatic cleavage. H. = 2–2·5. G. = 6·2. Luster metallic. Color and streak tin-white. B.B. wholly volatile. In warm concentrated sulphuric acid gives red solution. From Transylvania, West Australia, and a number of places in Colorado.

ANTIMONY.

Rhombohedral. Generally massive, lamellar and distinctly cleavable; also radiated; granular.

Cleavage: *c*(0001) highly perfect; also other cleavages. Fracture uneven; brittle. H = 3–3·5. G. = 6·65–6·72. Luster metallic. Color and streak tin-white.

Comp. — Antimony, containing sometimes silver, iron, or arsenic.

Pyr. — B.B. on charcoal fuses very easily and is wholly volatile giving a white coating. The white coating tinges the R.F. bluish green. Crystallizes readily from fusion.

Obs. — Occurs near Sala in Sweden; Andreasberg in the Harz Mts., Germany; Allemont, Dauphiné, France; Přibram, Bohemia; Mexico; Chile; Borneo. In the United States, at Warren, N. J., rare; in Kern Co., and at South Riverside, Cal. At South Ham, Quebec; Prince William parish, York Co., New Brunswick.

Use. — An ore of antimony.

BISMUTH.

Rhombohedral. Usually reticulated, arborescent; foliated or granular.

Cleavage: *c*(0001) perfect. Sectile. Brittle, but when heated somewhat malleable. H. = 2–2·5. G. = 9·70–9·83. Luster metallic. Streak and color silver-white, with a reddish hue; subject to tarnish. Opaque.

Comp. — Bismuth, with traces of arsenic, sulphur, tellurium, etc.

Pyr., etc. — B.B. on charcoal fuses very easily and entirely volatilizes, giving a coating orange-yellow while hot, lemon-yellow on cooling. With potassium iodide and sulphur B.B. on charcoal gives a brilliant red coating. Dissolves in nitric acid; subsequent dilution causes a white precipitate. Crystallizes readily from fusion.

Micro. — In polished section shows creamy white color with pink tinge. Smooth and metallic surface. With HCl slowly darkens and dissolves. Rapidly darkens with effervescence with HNO_3 and aqua regia.

Obs. — Occurs in veins in gneiss and other crystalline rocks and clay slate, accompanying various ores of silver, cobalt, lead and zinc. Thus at the mines of Saxony and Bohemia, etc.; Meymac, Corrèze, France. Also at Modum, Norway; at Falun, Sweden. In Cornwall and Devonshire; near Copiapo, Chile; Bolivia.

Occurs at Monroe, Conn.; Brewer's mine, Chesterfield district, S. C.; near Cummins City, and elsewhere in Col. Abundant with silver ores at Cobalt, Ontario.

Use. — An ore of bismuth.

Zinc. — Probably does not occur in the native state. In the laboratory it is obtained in hexagonal prisms with tapering pyramids; also in complex crystalline aggregates. It also appears to crystallize in the isometric system, at least in various alloys.

Tantalum. Isometric. In cubic crystals and fine grains. Color grayish yellow.

Found containing small amounts of niobium in the gold washings of the Ural and Altai Mts.

Gold Group

GOLD.

Isometric. Distinct crystals rare, *o*(111) most common, also *d*(110) and *m*(311); crystals often elongated in direction of an octahedral axis, giving rise to rhombohedral-like forms, and arborescent shapes; also in plates flattened || *o*(111), and branching at 60° parallel either to the edges or diagonals of an *o* face (see pp. 172, 173). Twins: tw. plane *o*. Skeleton crystals common; edges salient or rounded; in filiform, reticulated, dendritic shapes. Also massive and in thin laminæ; often in flattened grains or scales.

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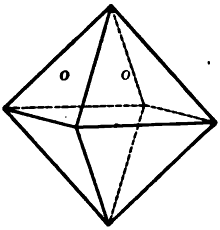

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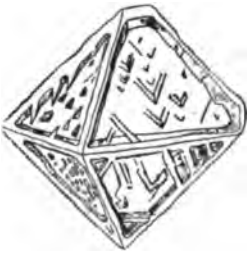

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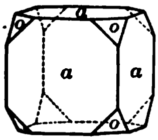

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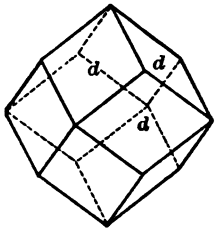

Cleavage none. Fracture hackly. Very malleable and ductile. H. = 2·5–3. G. = 15·6–19·3, 19·33 when pure. Luster metallic. Color and streak gold-yellow, sometimes inclining to silver-white and rarely to orange-red. Opaque.

Comp. — Gold, but usually alloyed with silver in varying amounts and sometimes containing also traces of copper or iron.

Var. — 1. *Ordinary.* Containing up to 16 p. c. of silver. Color varying accordingly from deep gold-yellow to pale yellow, and specific gravity from 19·3 to 15·5. The ratio of gold to silver of 3 : 1 corresponds to 15·1 p. c. silver. For G. = 17·6, Ag = 9 p. c.; G. = 16·9, Ag = 13·2; G. = 14·6, Ag = 38·4. The purest gold which has been described is that from Mount Morgan, in Queensland, which has yielded 99·7 to 99·8 of gold, the remainder being copper with a little iron; silver is present only as a minute trace.

2. *Argentiferous; Electrum.* Color pale yellow to yellowish white; G = 15·5–12·5. Ratio for the gold and silver of 1 : 1 corresponds to 36 p. c. of silver; 1½ : 1, to 26 p. c.; 2 : 1, to 21 p. c.; 2½ : 1, to 18 p. c. The word in Greek means also *amber;* and its use for this alloy probably arose from the pale yellow color it has as compared with gold.

Varieties have also been described containing copper up to 20 p. c. from the Ural Mts.; palladium to 10 p. c. (*porpezite*), from Porpez, Brazil; bismuth, including the black gold of Australia (*maldonite*); also rhodium(?).

Pyr., etc. — B.B. fuses easily (at 1100° C.). Not acted on by fluxes. Insoluble in any single acid; soluble in aqua regia, the separation not complete if more than 20 p. c. Ag is present.

Diff. — Readily recognized (*e.g.*, from other metallic minerals, also from scales of yellow mica) by its malleability and high specific gravity, which last makes it possible to separate it from the gangue by washing; distinguished from chalcopyrite and pyrite since both sulphides are brittle and soluble in nitric acid.

Micro. — In polished section shows a golden yellow color with a smooth, metallic surface. Unaffected by reagents except KCN, with which it quickly darkens and its surface becomes rough.

Obs. — Gold is widely distributed in the earth's crust. It has been found in various igneous rocks, more commonly in the acid types, and sometimes in visible particles. It occurs in sedimentary rocks and quite frequently in connection with metamorphic rocks.

It is a constituent of sea water. It is most frequently found in notable amounts in quartz veins and in the various forms of placer deposits.

The gold, when occurring in quartz, is often irregularly distributed, in strings, scales, plates, and in masses which are sometimes an agglomeration of crystals. Frequently the scales are invisible to the naked eye. The associated minerals are: pyrite, which far exceeds in quantity all others, and is generally *auriferous;* next, chalcopyrite, galena, sphalerite, arsenopyrite, each frequently auriferous; often tetradymite and other tellurium ores, native bismuth, native arsenic, stibnite, cinnabar, magnetite, hematite; sometimes barite, scheelite, apatite, fluorite, siderite, chrysocolla. The quartz at the surface, or in the upper part of a vein, is usually cellular and rusted from the more or less complete disappearance of the pyrite and other sulphides by decomposition; but below, it is commonly solid.

The gold of the world was early gathered, not directly from the quartz veins (the "quartz reefs" of Australia and Africa), but from the gravel and sand deposited in the valleys in auriferous regions, or on the slopes of the mountains or hills, whose rocks contain in some part, and generally not far distant, gold bearing veins. Such deposits are known as placer deposits. The gold is obtained by some method involving the use of a current of water and the separation of the gold from the sand and gravel by means of its high specific gravity. These hydraulic methods have been very extensively used in California and Alaska and indeed most of the gold of the Ural Mts., Brazil, Australia, and many other gold regions has come from such alluvial washings. At the present time, however, placer deposits are much less depended upon and in many regions all the gold is obtained directly from the rock.

The alluvial gold is usually in flattened scales of different degrees of fineness, the size depending partly on the original condition in the quartz veins, and partly on the distance to which it has been transported and assorted by running water. The rolled masses when of some size are called *nuggets;* in rare cases these occur very large and of great value. The Australian gold region has yielded many large nuggets; one of these found in 1858 weighed 184 pounds, and another (1869) weighed 190 pounds. In the auriferous sands, crystals of zircon are very common; also garnet and cyanite in grains; often also monazite, diamond, topaz, corundum, iridosmine, platinum.

Besides the free gold of the quartz veins and gravels, much gold is also obtained from auriferous sulphides or the oxides produced by their alteration, especially pyrite; also arsenopyrite, chalcopyrite, sphalerite, marcasite, etc. The only minerals containing gold in combination are the rare tellurides (sylvanite, calaverite, etc.).

Gold is widely distributed over the earth. It occurs under many different conditions and with many different rocks, being, however, more commonly associated with the acid types. A brief summary of the more important districts follows.

Europe. The gold deposits of Europe are to be found chiefly in three great districts, namely the Ural mountains, eastern Hungary and a less important Alpine district reaching from Carinthia through the Austrian Tyrol and the Italian Alps to the Pyrenees. There are three gold districts in Hungary. Two of these are of minor importance and lie one to the north of Buda-Pesth and the other near the Galician frontier. The third district, which is the most important district in Europe, is in Transylvania, lying in the southeastern portion of the Bihar mountains. Its important centers are Offenbanya, Verespatak, Nagyág (largely tellurides), Boicza and Ruda.

Asia. In Siberia gold is found on the eastern slope of the Ural mountains for a distance of 500 miles. The important districts from north to south are Bogoslov, Nizhni Tagilsk, Beresov and other localities near Ekaterinburg, Syserstk and Kyshtimsk, the Miask district including Zlatoust and Mt. Ilmen, Kotchkar and at the southern limit of the fields, Orsk. Siberia also has the important placer districts in Tomsk, which include Altai and Marinsk, and in Yeniseisk, the Atchinsk, Minusinsk and the north and south Yenisei districts. Farther east there are deposits in Transbaikalia and the Lena district in Yakutsk. In India the chief districts are the Kolar field near Bangalore in Mysore and the Gadag and Hutti districts a little further north. Gold has been mined in China in Chili, Shantung Weihaiwei, Szechuen, Yuman and Fo-Kien. In Manchuria on the Luau-tung Peninsula. In Korea principally at Unsan. Gold-quartz veins, many of which have been worked for a long time, occur on a number of the Japanese islands.

Australasia. The most important districts in New Zealand lie on the Hauraki Peninsula with the Waihi mine as the most famous. Other districts are the West Coast area on the western slopes of the Alps of the South Island and the Otago area. In Queensland the districts of Charter Towers and the Mount Morgan mine are important. There are many gold districts in New South Wales among which are Hillgrove, Mount Boppy and Hill End. Rich districts in Victoria are the Bendigo and Ballarat. The principal gold fields of Tasmania are Beaconsfield, Mathinna and the copper deposits at Mount Lyell. The chief gold field in West Australia is near Kalgoorlie where the ores are largely tellurides.

Africa. Gold is found in Egypt in the section between the Nile and the Red Sea. Some of these deposits were worked in very early days. Gold has been produced for a long time from the Gold Coast district on the Gulf of Guinea. Important deposits are found in Matabeleland and Mashonaland in Southern Rhodesia. The most important gold district in the world is that of the Witwatersrand in the Transvaal. The mines occur in an east and west belt, some sixty miles in length, near Johannesburg. The gold is found scattered in small amounts through a series of steeply dipping quartz conglomerate rocks.

South America. Colombia has in the past produced large amounts of gold. The chief districts today are in the states of Antioquia and Cauca. Comparatively small amounts are produced at the present time in the other northern countries. The important deposits of Brazil lie 200 miles to the north of Rio de Janeiro in Minas Geraes along the Sierra do Espinhaco. The gold deposits in Chile lie chiefly in the coast ranges in the northern and central parts of the country.

Mexico. While Mexico is chiefly noteworthy for its silver output it produces also considerable gold. Important districts are as follows: Altar, Magdalena and Arizpe in Sonora; various places in Chihuahua, especially about Parral, and the Dolores mine on the western border of the state; the El Oro mines in the state of Mexico; the Pachuca district in Hidalgo; also various places in Guanajuato and Zacatecas.

Canada. The three important placer districts of Canada are the Klondike in Yukon Territory and the Atlin and Cariboo in British Columbia. The most productive vein deposits are found in British Columbia in the West Kootenay and Yale districts. Gold is also found in Ontario and Nova Scotia.

United States. Gold occurs in the United States chiefly along the mountain ranges in the western states. Smaller amounts have been found along the Appalachians in the states of Virginia, North and South Carolina and Georgia. The more important localities in the western states are given below, the states being arranged approximately in the order of their importance. California. At the present time about two thirds of the state's output comes from the lode mines and one third from placer deposits. The quartz veins are chiefly found in what is known as the Mother-Lode belt that lies on the western slope of the Sierra Nevada and stretches from Mariposa County for more than 100 miles toward the north. The veins occur chiefly in a belt of slates. The lode mines are found chiefly in Amador, Calaveras, Kern, Nevada, Shasta, Sierra and Tuolumne Counties. The important placer mines are located in Butte, Sacramento and Yuba Counties. About 90 per cent of the placer gold is obtained by the use of dredges. Colorado. Gold is mined in various districts in Gilpin County, from the Leadville district and others in Lake County, in the region of the San Juan mountains in the Sneffels, Silverton and Telluride districts, Cripple Creek district (telluride ores) in Teller County, placer deposits in the Breckenridge district in Summit County. Alaska. The most important lode mines are in the Juneau district, while the chief placer deposits are those of Fairbanks and Iditarod in the Yukon basin and the Nome district on the Seward Peninsula. Nevada. The most important districts are those of Goldfield in Esmeralda County and Tonapah in Nye County. South Dakota. The output is chiefly from the Homestake mine at Lead in Lawrence County. Montana. There are various producing districts, the more important being in Madison (largely placers), Deer Lodge and Silver Bow Counties. Arizona. The important counties are Mohave and Cochise. Utah. Gold is produced chiefly from the Bingham and Tintic districts in Salt Lake County and from Juab County.

Use. — The chief ore of gold.

SILVER.

Isometric. Crystals commonly distorted, in acicular forms, reticulated or arborescent shapes; coarse to fine filiform; also massive, in plates or flattened scales.

Cleavage none. Ductile and malleable. Fracture hackly. H. = 2·5–3. G. = 10·1–11·1, pure 10·5. Luster metallic. Color and streak silver-white, often gray to black by tarnish.

Comp. — Silver, with some gold (up to 10 p. c.), copper, and sometimes platinum, antimony, bismuth, mercury.

Pyr., etc. — B.B. on charcoal fuses easily to a silver-white globule, which in O.F. gives a faint dark red coating of silver oxide; crystallizes on cooling; fusibility about 1050° C. Soluble in nitric acid, and deposited again by a plate of copper. Precipitated from its solutions by hydrochloric acid in white curdy forms of silver chloride.

Diff. — Distinguished by its malleability, color (on the fresh surface), and specific gravity.

Micro. — In polished section shows a creamy white color with a metallic, smooth surface. With aqua regia and $FeCl_3$ tarnishes quickly with bright iridescent colors. Blackens with HNO_3.

Obs.— Native silver occurs in masses, or in arborescent and filiform shapes, in veins traversing gneiss, schist, porphyry, and other rocks. Also occurs disseminated, but usually invisibly, in native copper, galena, chalcocite, etc. It is commonly of secondary origin, having been derived from the reduction of sulphides and other compounds of silver.

Native silver is found at a great many localities, some of the most famous of which follow: Kongsberg, Norway, in magnificent specimens and in very large masses; Freiberg, Schneeberg, etc., in Saxony; Přibram and Joachimstal in Bohemia; Andreasberg in the Harz Mts., Germany; Allemont in Dauphiné, France; at various points in Cornwall, England. At Chañarçillo and other localities in Chile; in large masses at Huantaya, Peru. In many places in Mexico, especially at Batopilas in Chihuahua; in Zacatecas and Guanajuato. A very important district is at Cobalt, Ontario, where native silver occurs in masses up to 1000 pounds in weight; it occurs there associated with various cobalt and nickel minerals.

In the United States it has been found with native copper in the Lake Superior copper district; at Silver Islet, Lake Superior; at Butte and the Elkhorn mine in Mon.; at the Poor Man's Lode in Idaho; in Col., with various sulphide deposits, especially at Aspen.

Use. — An ore of silver.

COPPER.

Isometric. The tetrahexahedron a common form (Fig. 635); also in octahedral plates. Distinct crystals rare. Frequently irregularly distorted and passing into twisted and wirelike forms; filiform and arborescent. Massive; as sand. Twins: tw. pl. *o* (111), very common, often flattened or elongated to spear-shaped forms. Cf. p. 173.

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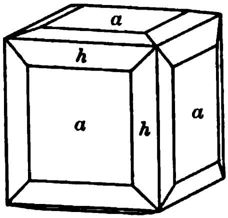


h = (410).

Cleavage none. Fracture hackly. Highly ductile and malleable. H. = 2·5–3. G. = 8·8–8·9. Luster metallic. Color copper-red. Streak metallic shining. Opaque. An excellent conductor for heat and electricity.

Comp. — Pure copper, often containing some silver, bismuth, mercury, etc.

Pyr., etc. — B.B. fuses readily; on cooling becomes covered with a coating of black oxide. Dissolves readily in nitric acid, giving off red nitrous fumes, and produces a deep azure-blue solution with excess of ammonia. Fusibility 780° C.

Micro. — In polished section shows pink color with smooth, metallic surface. With conc. HNO_3 dissolves and shows iridescent tarnish. With $FeCl_3$ blackens and shows a solution pit.

Obs. — Copper is usually, if not always, secondary in its origin. It has either been deposited from solution by some reducing agent which is commonly a compound of iron or by the gradual reduction of some solid compound. Pseudomorphs of copper after cuprite, azurite, chalcocite, etc., are well known. It is associated with other copper ores, especially cuprite, malachite and azurite in the upper zone of copper veins; also with the sulphides, chalcopyrite, chalcocite, etc.; often abundant in the vicinity of dikes of igneous rocks; also in clay slate and sandstone.

Occurs in crystals at Bogoslovsk, Nijni Tagilsk and elsewhere in the Ural Mts. In Nassau, Germany. Common in Cornwall, England. Occurs in Brazil, Chile, and Peru. Found in pseudomorphs after the pseudo-hexagonal twins of aragonite at Corocoro, Bolivia. Abundant at Wallaroo, South Australia and at Broken Hill, New South Wales. Occurs at various places in Mexico.

Occurs native throughout the red sandstone region of the eastern United States, sparingly in Mass., Conn., and more abundantly in N. J. Near New Haven, Conn., a mass was found in the drift weighing nearly 200 pounds; smaller isolated masses have also been found. Found in minor amounts at Bisbee, Ariz. (in branching crystal groups); at Georgetown, N. M. (pseudomorphs after azurite); Ducktown, Tenn.; Cornwall, Pa.; and Franklin, N. J. The most important region in the world for native copper is the Lake Superior copper district on the Keweenaw peninsula, northern Mich. The rocks of this district consist of a series of interbedded lava flows, sandstones and conglomerates which dip steeply to the northwest. The copper is obtained practically all in the native state, sometimes in immense masses. It occurs as (1) a cement filling the interstices in the sandstone and conglomerate, sometimes replacing in large part the grains and pebbles themselves, (2) filling the amygdaloidal cavities in the diabase and (3) in veins that traverse all kinds of rock. The copper was probably brought into the district by the igneous rocks. It is associated with native silver, calcite, prehnite, datolite, analcite, etc.

Use. — An ore of copper.

MERCURY. Quicksilver.

In small fluid globules scattered through its gangue. G = 13·6. Luster metallic, brilliant. Color tin-white. Opaque.

Comp. — Pure mercury (Hg); with sometimes a little silver.

Pyr., etc. — B.B. entirely volatile, vaporizing at 350° C. Becomes solid at − 40° C., crystallizing in regular octahedrons with cubic cleavage; G. = 14·4. Dissolves in nitric acid.

Obs. — Mercury in the metallic state is a rare mineral, and is usually associated with the sulphide cinnabar, from which the supply of commerce is obtained. The rocks affording the metal and its ores are chiefly clay shales or schists of different geological ages. Also found in connection with hot springs. See cinnabar.

LEAD.

Isometric. Crystals rare. Usually in thin plates and small globular masses. Very malleable, and somewhat ductile. H = 1·5. G. = 11·4. Luster metallic. Color lead-gray. Opaque.

Comp. — Nearly pure lead; sometimes contains a little silver, also antimony.

Pyr. — B.B. fuses easily, coating the charcoal with a yellow to white oxide. Fusibility 330° C. Dissolves easily in dilute nitric acid.

Obs. — Of rare occurrence. Found at Pajsberg, Harstig, and Långban in Sweden; similarly at Nordmark; also in the gold washings of the Ural Mts.; reported elsewhere, but localities often doubtful. In the United States, occurs at Breckinridge and Gunnison, Col.; Wood River district, Idaho; Franklin, N. J.

AMALGAM.

Isometric. Common habit dodecahedral. Crystals often highly modified. Also massive in plates, coatings, and embedded grains.

Cleavage: dodecahedral in traces. Fracture conchoidal, uneven. Rather brittle to malleable. H. = 3–3·5. G. = 13·75–14·1. Luster metallic, brilliant. Color and streak silver-white. Opaque.

Comp. — (Ag,Hg), silver and mercury, varying from Ag_2Hg_3 to $Ag_{36}Hg$.

Var. — *Ordinary amalgam,* Ag_2Hg_3 (silver 26·4 p. c.) or AgHg (silver 35·0); also Ag_5Hg_3, etc. *Arquerite,* $Ag_{12}Hg$(silver 86·6); G. = 10·8; malleable and soft. *Kongsbergite,* Ag_xHg or $Ag_{36}Hg$.

Pyr., etc. — B.B. on charcoal the mercury volatilizes and a globule of silver is left. In the closed tube the mercury sublimes and condenses on the cold part of the tube in minute globules. Dissolves in nitric acid. Rubbed on copper it gives a silvery luster.

Obs. — From Germany in the Rhine-Palatinate at Moschel-Landsberg and at Friedrichssegen, Nassau; from Sala, Sweden; Kongsberg, Norway; Allemont, Dauphiné, France; Almaden, Spain; Chile; Vitalle Creek, British Columbia (*arquerite*).

Tin. — Native tin has been reported from several localities. The only occurrence fairly above doubt is that from the washings at the headwaters of the Clarence river, near Oban, New South Wales. It has been found here in grayish white rounded grains, with platinum, iridosmine, gold, cassiterite, and corundum.

Platinum-Iron Group

PLATINUM.

Isometric. Crystals rare; usually in grains and scales.

Cleavage none. Fracture hackly. Malleable and ductile. H. = 4–4·5. G. = 14–19 native; 21–22 chem. pure. Luster metallic. Color and streak whitish steel-gray; shining. Sometimes magnetic and occasionally shows polarity.

Comp. — Platinum alloyed with iron, iridium, rhodium, palladium, osmium, and other metals.

Most platinum yields from 8 to 15 or even 18 per cent of iron, 0·5 to 2 p. c. palladium, 1 to 3 p. c. each of rhodium and iridium, a trace of osmium and finally 0·5 to 2 p. c. or more of copper.

Var. — 1. *Ordinary. Non-magnetic* or only slightly magnetic. G. = 16·5–18·0 mostly. 2. *Magnetic.* G. about 14. Much platinum is magnetic, and occasionally it has polarity. The magnetic property seems to be connected with high percentage of iron (iron-platinum), although this distinction does not hold without exception.

Pyr., etc. — B.B. infusible. Not affected by borax or salt of phosphorus, except in the state of fine dust, when reactions for iron and copper may be obtained. Soluble only in heated aqua regia.

Diff. — Distinguished by its color, malleability, high specific gravity, infusibility and insolubility in ordinary acids.

Obs. — The platinum of commerce comes almost exclusively from placer deposits. Its original source, however, is in the basic igneous rocks, usually peridotites. The associated minerals are commonly chrysolite, serpentine and chromite. Platinum was first found in pebbles and small grains, associated with iridium, gold, chromite, etc., in the alluvial deposits of the river Pinto, in the district of El Choco, Colombia ; South America, where it received its name *platina* (platina del Pinto) from *plata*, silver. The greater part of the world's supply comes from Russia (discovered in 1822) where it occurs in alluvial material in the Ural Mts. at Nijni Tagilsk, and with chromite in a serpentine probably derived from a peridotite; also in the Goroblagodat and Bisersk districts. Also found in Borneo; in New Zealand, from a region characterized by a chrysolite rock with serpentine; in New South Wales, at the Broken Hill district, and in gold washings at various points.

In Cal. in small amounts in the gold placers, chiefly in Trinity Co.; at Port Orford in Ore. At various points in Canada, the most important being the Tulameen District in British Columbia

Use. — Practically the only ore of platinum.

Iridium. Platin-iridium. Iridium alloyed with platinum and other allied metals. Occurs usually in angular grains of a silver-white color. H. = 6–7. G. = 22·6–22·8. With the platinum of the Ural Mts. and Brazil.

IRIDOSMINE. Osmiridium.

Rhombohedral. Usually in irregular flattened grains.

Cleavage: *c*(0001) perfect. Slightly malleable to nearly brittle. H. = 6–7. G. = 19·3–21·12. Luster metallic. Color tin-white to light steel-gray. Opaque.

Comp. — Iridium and osmium in different proportions. Some rhodium, platinum, ruthenium, and other metals are usually present.

Var. — 1. *Nevyanskite.* H. = 7; G. = 18·8–19·5. In flat scales; color tin-white. Over 40 p. c. of iridium. 2. *Siserskite.* In flat scales, often six-sided, color grayish white, steel-gray. G. = 20–21·2. Not over 30 p. c. of iridium. Less common than the light-colored variety.

Diff. — Distinguished from platinum by greater hardness and by its lighter color.

Obs. — Occurs with platinum in South America; in the Ural Mts.; in auriferous drift in New South Wales. Rather abundant in the auriferous beach-sands of northern California and Oregon.

Palladium. — Isometric. Palladium, alloyed with a little platinum and iridium.

Mostly in grains. H. = 4·5–5. G. = 11·3–11·8. Color whitish steel-gray. Occurs with platinum in Brazil; also from the Ural Mts.

Allopalladium. — Palladium under the hexagonal-rhombohedral class(?). From Tilkerode in the Harz Mts. in small hexagonal tables with gold.

IRON.

Isometric. Usually massive, rarely in crystals.

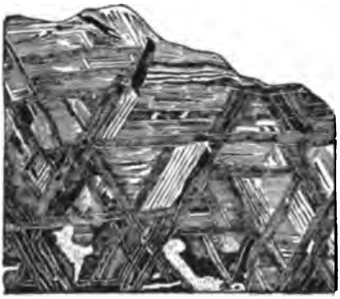
Cleavage: $a(100)$, perfect; also a lamellar structure $\parallel o(111)$ and $\parallel d(110)$. Fracture hackly. Malleable. H. = 4–5. G. = 7·3–7·8. Luster metallic. Color steel-gray to iron-black. Strongly magnetic.

Var. — 1. **Terrestrial Iron.** — Found in masses, occasionally of great size, as well as in small embedded particles, in basalt at Blaafjeld, Ovifak (or Uifak), Disko Island, West Greenland; also elsewhere on the same coast. This iron contains 1 to 2 p. c. of Ni. In small grains with pyrrhotite in basalt from near Kassel, Hesse Nassau, Germany. In minute spherules in feldspar from Cameron Township, Nipissing Dist., Ontario. Some other occurrences, usually classed as meteoric, may be in fact terrestrial.

A nickeliferous metallic iron ($FeNi_2$) called *awaruite* occurs in the drift of the Gorge river, which empties into Awarua Bay on the west coast of the south island of New Zealand; associated with gold, platinum, cassiterite, chromite; probably derived from a partially serpentinized peridotite. *Josephinite* is a nickel-iron ($FeNi_3$) from Oregon, occurring in stream gravel. Similar material from near Lillooet on the Fraser river, British Columbia, has been called *soucsite*. Native iron also occurs sparingly in some basalts; reported from gold or platinum washings at various points.

2. **Meteoric Iron.** — Native iron also occurs in most meteorites, forming in some cases (*a*) the entire mass (*iron meteorites*); also (*b*) as a spongy, cellular matrix in which are embedded grains of chrysolite or other silicates (*siderolites*); (*c*) in grains or scales disseminated more or less freely throughout a stony matrix (*meteoric stones*). Rarely a meteorite consists of a single crystalline individual with numerous twinning lamellæ $\parallel o(111)$. Cubic cleavage sometimes observed; also an octahedral, less often dodecahedral, lamellar structure. Etching with dilute nitric acid (or iodine) commonly develops a crystalline structure (called *Widmanstätten figures*) (Fig. 636); usually consisting of lines or bands crossing at various angles according to the direction of the section, at 60° if $\parallel o(111)$, 90° $\parallel a(100)$, etc. They are formed by the edges of crystalline plates, usually $\parallel o$, of the nickeliferous iron of different composition (*kamacite*, *tænite*, *plessite*), as shown by the fact that they are differently attacked by the acid. Irons with cubic structure and with twinning lamellæ have a series of fine lines corresponding to those developed by etching (*Neumann lines*). A damascene luster is also produced in some cases, due to quadrilateral depressions. Some irons show no distinct crystalline structure upon etching.

636



Glorieta Mt., New Mexico

The exterior of masses of meteoric iron is usually more or less deeply pitted with rounded thumblike depressions, and the surface at the time of fall is covered with a film of iron oxide in fine ridges showing lines of flow due to the melting caused by the heat developed by the resistance of the air; this film disappears when the iron is exposed to the weather.

Meteoric iron is always alloyed with nickel, which is usually present in amounts varying from 5 to 10 p. c., sometimes much more; small amounts of other metals, as cobalt, manganese, tin, copper, chromium, are also often present. Occluded gases can usually be detected. Graphite, in seams or nodules, also troilite (iron sulphide), schreibersite (iron-nickel phosphide) are common in masses of meteoric iron; diamond, daubreelite, etc., are rare. *Cohenite*, sometimes identified, is $(Fe,Ni,Co)_3C$ in tin-white crystals.

Moissanite. — CSi. This material, originally produced artificially as *carborundum*, has been found occurring naturally as small green hexagonal plates in the meteoric iron of Cañon Diablo, Ariz

II. SULPHIDES, SELENIDES, TELLURIDES, ARSENIDES, ANTIMONIDES

The sulphides, etc., fall into two Groups according to the character of the positive element.

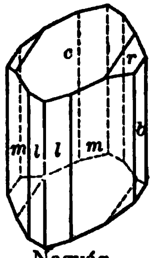
I. Sulphides, Selenides, Tellurides of the Semi-metals.

II. Sulphides, Selenides, Tellurides, Arsenides, Antimonides of the Metals.

I. Sulphides, etc., of the Semi-Metals

This section includes one distinct group, the Stibnite Group, to which orpiment is related; the other species included stand alone.

637



Nagyág

REALGAR.

Monoclinic. Axes $a : b : c = 1{\cdot}4403 : 1 : 0{\cdot}9729$; $\beta = 66° 5'$.
mm''', $110 \wedge 1\bar{1}0 = 105° 34'$. rr', $012 \wedge 0\bar{1}2 = 47° 57'$.

Crystals short prismatic; striated vertically. Also granular, coarse or fine; compact; as an incrustation.

Cleavage: *b*(010) rather perfect. Fracture small conchoidal. Sectile. H. = 1·5–2. G. = 3·56. Luster resinous. Color aurora-red or orange-yellow. Streak varying from orange-red to aurora-red. Transparent — translucent.

Comp. — Arsenic monosulphide, AsS = Sulphur 29·9, arsenic 70·1 = 100.

Pyr., etc. — In the closed tube melts and gives a dark red liquid when hot and a reddish yellow solid when cold; in the open tube (if heated very slowly) sulphurous fumes, and a white crystalline sublimate of arsenic trioxide. B.B. on charcoal burns with a blue flame, emitting arsenical and sulphurous odors. Soluble in caustic alkalies.

Artif. — Realgar is frequently noted as a sublimation product from furnaces roasting ores of arsenic. Crystals are produced when arsenic sulphide is heated in a sealed tube with a solution of sodium bicarbonate.

Obs. — Realgar occurs usually in veins associated with silver and lead ores. It has been found in volcanic regions as a sublimation product. It has also been noted as a deposit from hot spring waters. It is often associated with orpiment. It occurs at Felsöbánya, Kapnik and Nagyág, Hungary; Allchar, Macedonia. Binnental, Switzerland, in dolomite. In the United States, at Mercur, Utah; in the Norris Geyser Basin, Yellowstone Park, as a deposition from the hot waters. Found at the Monte Cristo mining district, Snohomish Co., Washington; the name *realgar* is from the Arabic, Rahj al ghār, *powder of the mine.*

Use. — Was used in fireworks to give a brilliant white light when mixed with saltpeter and ignited. The artificial material is now used for this purpose.

ORPIMENT.

Monoclinic. Axes $a : b : c = 0{\cdot}596 : 1 : 0{\cdot}665$, $\beta = 90°41'$.

Crystals small, rarely distinct. Usually in foliated or columnar masses; sometimes with reniform surface.

Cleavage: *b*(010) highly perfect, cleavage face vertically striated; *a*(100) in traces; gliding-plane *c* (001). Sectile. Cleavage laminæ flexible, inelastic. H. = 1·5–2. G. = 3·4–3·5. Luster pearly on *b* (cleavage); elsewhere resinous. Color lemon-yellow of several shades; streak the same, but paler. Subtransparent — subtranslucent.

Comp. — Arsenic trisulphide, As_2S_3 = Sulphur 39·0, arsenic 61·0 = 100.

Pyr., etc. — Same as for realgar, p. 357.

Diff. — Distinguished by its fine yellow color, pearly luster, easy cleavage, and flexibility when in plates.

Artif. — Orpiment has been synthesized by heating solutions of arsenic with ammonium sulphocyanate in a sealed tube; also by the treatment under pressure of arsenic acid with hydrogen sulphide.

Obs. — Occurs under same conditions as realgar with which it is commonly associated. It is found in Hungary at Tajowa in small crystals, in foliated and fibrous masses at Moldowa, in metalliferous veins at Kapnik and Felsőbánya; with realgar at Allchar, Macedonia. A large deposit occurred near Julamerk in Kurdistan. Occurs in fine crystals at Mercur, Utah. Among the deposits of the Steamboat Springs, Nevada; also with realgar in the Yellowstone Park.

The name orpiment is a corruption of its Latin name auripigmentum, "*golden paint*," given in allusion to the color, and also because the substance was supposed to contain gold.

Use. — For a pigment, in dyeing and in a preparation for the removal of hair from skins. The artificial material is largely used as a substitute for the mineral.

Stibnite Group

		$a : b : c$
Stibnite	Sb_2S_3	0·9926 : 1 : 1·0179
Bismuthinite	Bi_2S_3	0·9679 : 1 : 0·9850
Guanajuatite	Bi_2Se_3	1 : 1 approx.

The species of the Stibnite Group crystallize in the orthorhombic system and have perfect brachypinacoidal cleavage, yielding flexible laminæ.

The species orpiment is in physical properties somewhat related to stibnite, but is monoclinic in crystallization. Groth notes that in a similar way, the oxide, As_2O_3, is monoclinic in claudetite, while the corresponding compound, Sb_2O_3 (valentinite), is orthorhombic.

STIBNITE. Antimonite, Antimony Glance.

Orthorhombic. Axes $a : b : c$ = 0·9926 : 1 : 1·0179.

mm''', $110 \wedge 1\bar{1}0$ = 89° 34'.
pp', $111 \wedge \bar{1}11$ = 71° 24⅓'.
ss', $113 \wedge \bar{1}13$ = 35° 52⅓'.
ss''', $113 \wedge 1\bar{1}3$ = 35° 36'.

bv, $010 \wedge 121$ = 35° 8'.
bη, $010 \wedge 353$ = 40° 10⅓'.
bτ, $010 \wedge 343$ = 46° 33'.
bp, $010 \wedge 111$ = 54° 36'.

Crystals prismatic; striated or furrowed vertically; often curved or twisted (cf. p. 188). Common in confused aggregates or radiating groups of acicular crystals; massive, coarse or fine columnar, commonly bladed, less often granular to impalpable.

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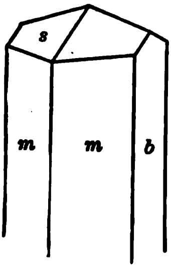
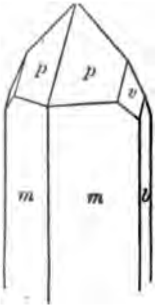


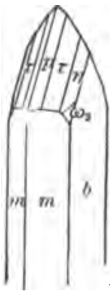
California

639



Hungary

640



Japan

Cleavage: *b* (010) highly perfect. Slightly sectile. Fracture small sub-conchoidal. H. = 2. G. = 4·52–4·62. Luster metallic, highly splendent on cleavage or fresh crystalline surfaces. Color and streak lead-gray, inclining to steel-gray: subject to blackish tarnish, sometimes iridescent.

Comp. — Antimony trisulphide, Sb_2S_3 = Sulphur 28·6, antimony 71·4 = 100. Sometimes auriferous, also argentiferous.

Pyr., etc. — Fuses very easily (at 1), coloring the flame greenish blue. In the open tube sulphurous (SO_2) and antimonial (chiefly Sb_2O_4) fumes, the latter condensing as a white sublimate which B.B. is non-volatile. On charcoal fuses, spreads out, gives sulphurous fumes, and coats the coal white with oxide of antimony; this coating treated in R.F. volatilizes and tinges the flame greenish blue. When pure, perfectly soluble in hydrochloric acid; in nitric acid decomposed with separation of antimony pentoxide.

Diff. — Distinguished (*e.g.*, from galena) by cleavage, color, softness; also by its fusibility and other blowpipe characters. It is harder than graphite. Resembles sometimes certain of the rarer sulphantimonites of lead, but yields no lead coating on charcoal.

Micro. — In polished section shows white color like galena with a smooth surface. Darkens with HNO_3 and aqua regia; with KOH turns orange-yellow to reddish brown.

Artif. — Stibnite, like orpiment, has been artificially produced by heating in a sealed tube, a solution of antimony with ammonium sulphocyanate; also by passing hydrogen sulphide at a red heat over compounds of antimony.

Obs. — Stibnite has been noted in deposits of solfataric origin but usually has apparently been deposited from alkaline solutions in intimate association with quartz. It is found in beds or veins in granite and gneiss, often accompanied with various other antimony minerals produced by its alteration. Also associated in metalliferous deposits with sphalerite, galena, cinnabar, barite, quartz; sometimes accompanies native gold.

Stibnite is the most common ore of antimony and is found in quantity in many countries but has never been extensively mined in the United States. In Europe it has been found in notable deposits at Wolfsberg, Harz Mts.; at Bräunsdorf near Freiberg in Saxony; at the Caspari mine near Arnsberg, Westphalia; in Hungary at Felsöbánya, Kremnitz and Kapnik; at various points in France. Groups of large splendent crystals have come from the antimony mines in the Province of Iyo, island of Shikoku, Japan. Important deposits are located in southern China, particularly in the Province of Hunan. Mexico and Chile produce considerable antimony ore.

In the United States the more important deposits are in Cal., on Telescope Peak in the Panamint Range, in Kern County and in the eastern part of San Benito County. Nev. has several deposits, mostly in the northwest section.

Use. — The most important ore of antimony.

Metastibnite. — An amorphous brick-red deposit of antimony trisulphide, Sb_2S_3, occurring with cinnabar and arsenic sulphide upon siliceous sinter at Steamboat Springs, Washoe Co., Nev.

BISMUTHINITE. Bismuth Glance.

Orthorhombic. Rarely in acicular crystals. *mm'''*, 110 ∧ 110 = 88° 8'. Usually massive, foliated or fibrous.

Cleavage: *b*(010) perfect. Somewhat sectile. H. = 2. G. = 6·4–6·5. Luster metallic. Streak and color lead-gray, inclining to tin-white, with a yellowish or iridescent tarnish. Opaque.

Comp. — Bismuth trisulphide, Bi_2S_3 = Sulphur 18·8, bismuth 81·2 = 100. Sometimes contains a little copper and iron.

Pyr., etc. — Fusibility = 1. In the open tube sulphurous fumes, and a white sublimate which B.B. fuses into drops, brown while hot and opaque yellow on cooling. On charcoal at first gives sulphurous fumes; then fuses with spirting, and coats the coal with yellow bismuth oxide; with potassium iodide and sulphur gives a yellow to bright red coating of bismuth iodide. Dissolves readily in hot nitric acid, and a white precipitate of a basic salt falls on diluting with water.

Artif. — Bismuthinite has been produced artificially by treating the volatilized chloride of bismuth with hydrogen sulphide; in crystals by heating bismuth sulphide in a sealed tube with an alkaline sulphide.

Micro. — In polished section shows white color like galena with a smooth surface, with HNO_3 blackens, leaving a rough surface; with aqua regia slowly turns brown.

Obs. — Found in Cornwall, England, at Carrock Fells, Redruth, etc.; in France at Meymac, Corrèze; in Saxony at Schneeberg and Altenberg; in Hesse at Bieber; in Hungary at Rézbánya and Oravicza; in Sweden at Riddarhyttan; in Bolivia at San Baldamero near Sovata and in the Chorolque and Tazna districts. Occurs in the United States in Beaver Co., Utah; in Rowan and Jackson Cos., N. C.; at Wicks, Jefferson Co., Mon.; Delaware Co., Pa.; Haddam, Conn.

Use. — An ore of bismuth.

Guanajuatite. Frenzelite. Bismuth selenide, Bi_2Se_3, sometimes with a small amount of sulphur replacing selenium. In acicular crystals; also massive, granular, foliated or fibrous. Cleavage: *b*(010) distinct. H. = 2·5–3·5. G. = 6·25–6·62. Luster metallic.

Color bluish gray. From the Santa Catarina mine, near Guanajuato, Mexico. Noted from Salmon, Idaho.

TETRADYMITE.

Rhombohedral. Crystals small, indistinct. Commonly in bladed forms foliated to granular massive.

Cleavage: basal, perfect. Laminæ flexible; not very sectile. H. = 1·5–2; soils paper. G. = 7·2–7·6. Luster metallic, splendent. Color pale steel-gray.

Comp. — Consists of bismuth and tellurium, with sometimes sulphur and a trace of selenium; the analyses for the most part afford the general formula $Bi_2(Te, S)_3$.

Var. — 1. *Free from sulphur.* Bi_2Te_3 = Tellurium 48·1, bismuth 51·9. G. = 7·642 from Dahlonega. Var. 2. *Sulphurous.* $2Bi_2Te_3 . Bi_2S_3$ = Tellurium 36·4, sulphur 4·6, bismuth 59·0 = 100. This is the more common variety and includes the *tetradymite* in crystals from Schubkau.

Pyr. — In the open tube a white sublimate of tellurium dioxide, which B.B. fuses to colorless drops. On charcoal fuses, gives white fumes, and entirely volatilizes; tinges the R.F. bluish green; coats the coal at first white (TeO_2), and finally orange-yellow (Bi_2O_3); some varieties give sulphurous and selenous odors.

Obs. — Occurs in Hungary at Schubkau near Schemnitz at Rézbánya and Orawitza; at Carrock Fells, Cumberland, England. Occurs on Liddell Creek, Kaslo river, West Kootenay, British Columbia. In the United States, in Va., at the Whitehall gold mines, Spottsylvania Co.; in Davidson Co., N. C., and in the gold washings of Burke and McDowell counties, etc.; near Dahlonega, Ga.; in Mon. At the Montgomery mine and near Bradshaw, Ariz. Named from τετρ΄δυμος, *fourfold*, in allusion to complex twin crystals sometimes observed.

Grünlingite. — Bi_4TeS_3. Massive. One distinct cleavage. Color, gray. G. = 7·321. From Cumberland, England. *Oruetite* is a similar mineral, Bi_8TeS_4, from Serrania de Ronda, Spain.

Josëite. — A bismuth telluride (Te 80 p. c., also S and Se). G. = 7·9. San José, Brazil.

Wehrlite. — A foliated bismuth telluride (Te 30 p. c.) of doubtful formula. G. = 8·4. Deutsch-Pilsen, Hungary.

MOLYBDENITE.

Crystals hexagonal in form, tabular, or short prisms slightly tapering and horizontally striated. Commonly foliated, massive or in scales; also fine granular.

Cleavage: basal eminent. Laminæ very flexible, but not elastic. Sectile. H. = 1–1·5. G. = 4·7–4·8. Luster metallic. Color pure lead-gray; a bluish gray trace on paper. Opaque. Feel greasy.

Comp. — Molybdenum disulphide, MoS_2 = Sulphur 40·0, molybdenum 60·0 = 100.

Pyr., etc. — In the open tube sulphurous fumes and a pale yellow crystalline sublimate of molybdenum trioxide (MoO_3). B.B. in the forceps infusible, imparts a yellowish green color to the flame; on charcoal the pulverized mineral gives in O.F. a strong odor of sulphur dioxide and coats the coal with crystals of molybdic oxide, yellow while hot, white on cooling; near the assay the coating is copper-red, and if the white coating be touched with an intermittent R.F., it assumes a beautiful azure-blue color. Decomposed by nitric acid, leaving a white or grayish residue.

Diff. — Much resembles graphite in softness and structure (see p. 347), but has a bluer trace on paper and readily yields sulphur fumes on charcoal.

Artif. — Molybdenite has been made artificially by adding molybdic oxide to a fused mixture of potassium carbonate and sulphur; also by heating a mixture of molybdates and lime in an atmosphere of hydrochloric acid and hydrogen sulphide.

Micro. — In polished section shows grayish white color with smooth surface. Unaffected by reagents.

Obs. — Generally occurs embedded in, or disseminated through, granite, gneiss, zircon-syenite, granular limestone, and other crystalline rocks. At Arendal and Laurvik in Norway; Altenberg, Saxony; Zinnwald and Schlaggenwald, Bohemia; near Miask, Ural Mts.; Chessy in France; in Italy, on island of Sardinia; Carrock Fells, in Cumberland; at several of the Cornish mines. In large crystals at Kingsgate, Glen Innes, N. S. W.

In Me. at Blue Hill Bay; in Conn., at Haddam, in gneiss; in Ver., at Newport; in N. H., at Westmoreland; in N. Y., two miles southeast of Warwick; in N. J., at Franklin; in Pa., in Chester, near Reading and at Frankford; near Concord, Cabarrus Co., N. C.; in quartz vein at Crown Point, Wash. Molybdenite has been mined in various places in Ariz., Col., Nev., Mon., Tex., Utah, etc. In Canada, at St. Jérôme, Quebec; in large crystals in Renfrew county, Ontario; also in Aldfield township, Pontiac Co., Quebec.

Named from *μόλυβδος*, *lead*; the name, first given to some substances containing lead, later included graphite and molybdenite, and even some compounds of antimony. The distinction between graphite and molybdenite was established by Scheele in 1778–79.

Use. — An important ore of molybdenum.

Tungstenite. — Probably WS_2. Earthy or foliated. Color and streak, dark lead-gray. H. = 2·5. G. = 7·4. Found at Emma mine, Salt Lake Co., Utah.

Patronite. Rizopatronite. — Complex composition, containing large amounts of a vanadium sulphide, perhaps VS_4. Amorphous. Color black. Occurs in a complex mixture of mineral substances among which are *quisqueite* and *bravoite*, at Minasragra, Peru.

II. Sulphides, Selenides, Tellurides, Arsenides, Antimonides of the Metals

The sulphides of this second section fall into four divisions depending upon the proportion of the negative element present. These divisions with the groups belonging to them are as follows:

A. Basic Division

B. Monosulphides, Monotellurides, etc., R_2S, $\overset{II}{R}S$, etc.

1. *Galena Group.* Isometric-normal.
2. *Chalcocite Group.* Orthorhombic.
3. *Sphalerite Group.* Isometric-tetrahedral.
4. *Cinnabar — Wurtzite — Millerite Group.* Hexagonal and rhombohedral.

C. Intermediate Division

Embraces Melonite, Te_2S_3; Bornite, $5Cu_2S.Fe_2S_3$; Linnæite, $CoS.Co_2S_3$; Chalcopyrite, $Cu_2S.Fe_2S_3$; etc.

D. Disulphides, Diarsenides, etc., RS_2, RAs_2, etc.

1. *Pyrite Group.* Isometric-pyritohedral.
2. *Marcasite Group.* Orthorhombic.

A. Basic Division

The basic division embraces several rare basic compounds of silver, copper or nickel chiefly with antimony and arsenic. Of these the crystallization of dyscrasite and maucherite only is known.

DYSCRASITE.

Orthorhombic. Axes $a : b : c = 0·5775 : 1 : 0·6718$. Crystals rare, pseudohexagonal in angles (mm''', $110 \wedge 1\bar{1}0 = 60° 1'$) and by twinning. Also massive. Fracture uneven. Sectile. H. = 3·5–4. G. = 9·44–9·85. Luster metallic. Color and streak silver-white, inclining to tin-white; sometimes tarnished yellow or blackish. Opaque.

Comp. — A silver antimonide, including Ag_3Sb = Antimony 27·1, silver 72·9 = 100, and Ag_6Sb = Antimony 15·7, silver 84·3 = 100, and perhaps other compounds.

Analyses vary widely, some conforming also to Ag_3Sb, $Ag_4(Sb,As)_3$, etc. By some authors classed with chalcocite.

Pyr., etc. B.B. on charcoal fuses (1·5) to a globule, coating the coal with white antimony trioxide and finally giving a globule of almost pure silver. Soluble in nitric acid, leaving antimony trioxide.

Obs. — Occurs near Wolfach, Baden; Andreasberg in the Harz Mts., Germany; Allemont, France. Noted at Cobalt, Ontario, Canada. Also from Mexico and Chile. Named from *δύσκρασις, a bad alloy*.

HUNTILITE, ANIMIKITE. The ores from Silver Islet, Lake Superior, apparently contain a silver arsenide (*huntilite*, Ag_3As?) and perhaps also a silver antimonide (*animikite*, Ag_9Sb?), the latter probably a mixture.

Horsfordite. A silver-white, massive copper antimonide, probably Cu_6Sb (Sb 24 p. c.). G. = 8·8. Asia Minor, near Mytilene.

Domeykite. — Copper arsenide, Cu_3As. Reniform and botryoidal; also massive, disseminated. G. = 7·2–7·75. Luster metallic. Color tin-white to steel-gray, readily tarnished. From several Chilian mines; also Zwickau, Saxony. In North America, with niccolite at Michipicoten Island, Lake Superior. Microscopic examination shows this mineral to be an intimate mixture of two unknown constituents. Usually identical with algodonite.

Mohawkite. — Like domeykite, Cu_3As, with Ni and Co. Massive, fine granular to compact. Color gray with faint yellow tinge; tarnishes to dull purple. H. = 3·5. Brittle. G. = 8·07. Microscopic examination shows it to be a mixture. From Mohawk mine, Keweenaw Co., Mich. *Ledouxite* from the Mohawk mine said to be Cu_4As has been shown to be a mixture.

Algodonite. Copper arsenide, Cu_6As (As 16·5 p. c.); G. = 7·62. Resembles domeykite. From Chile; also Lake Superior. Microscopic examination shows this mineral to be a mixture of two constituents.

Whitneyite. Copper arsenide, Cu_9As (As 11·6 p. c). G. = 8·4–8·6. Color pale reddish white. From Houghton Co., Mich.; Sonora, Lower California.

Chilenite. Perhaps Ag_6Bi. Copiapo, Chile.

COCINERITE. Copper, silver sulphide, Cu_4AgS. Massive. Color silver-gray, tarnishing black, H = 2·5. G. = 6·1. From Cocinera mine, Ramos, San Luis Potosi, Mexico.

Stützite. A rare silver telluride (Ag_4Te?). Probably from Nagyág, Transylvania.

Rickardite. Cu_4Te_3. Massive. H. = 3·5. G. = 7·5. Color deep purple, dulling on exposure. Fusible. Found at Vulcan, Col.

Maucherite. Ni_3As_2. Tetragonal. Habit, square tabular. H. = 5. G. = 7·83. Color reddish silver-white tarnishing to gray copper-red. Streak blackish gray. Easily fusible. From Eisleben, Thuringia. The furnace product, *placodine*, is identical with *maucherite*.

B. Monosulphides, Monotellurides, etc., $\overset{\text{I}}{R}_2S$, $\overset{\text{II}}{R}S$, ETC.

1. *Galena Group.* Isometric.

Galena	PbS	**Argentite**	Ag_2S
Also,	$(Pb,Cu_2)S$, $(Cu_2,Pb)S$	Jalpaite	$(Ag,Cu)_2S$
Altaite	PbTe	**Hessite**	Ag_2Te
Clausthalite	PbSe	**Aguilarite**	Ag_2Se
Naumannite	$(Ag_2,Pb)Se$		

The following, known only in massive form, probably also belong here:

Berzelianite	Cu_2Se	**Zorgite**	$(Pb,Cu_2,Ag_2)Se$?
Lehrbachite	$(Pb,Hg_2)Se$	**Crookesite**	$(Cu,Tl,Ag)_2Se$
Eucairite	$Cu_2Se.Ag_2Se$		

The Galena Group embraces a number of monosulphides, etc., of the related metals, silver, copper, lead, and mercury. These crystallize in the normal class of the isometric system, and several show perfect cubic cleavage. These characters are most distinctly exhibited in the type species, galena.

GALENA. Galenite. Lead glance.

Isometric. Commonly in cubes, or cubo-octahedrons, less often octahedral. Also in skeleton crystals, reticulated, tabular. Twins: tw. pl. *o*(111), both contact- and penetration-twins (Figs. 401, 404, p. 165), sometimes repeated; twin crystals often tabular || *o*. Also other tw. planes giving polysynthetic tw. lamellæ. Massive cleavable, coarse or fine granular, to impalpable; occasionally fibrous or plumose.

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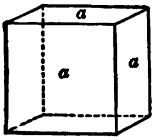

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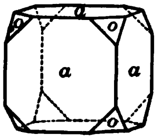

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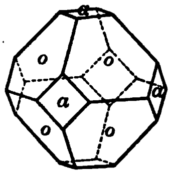

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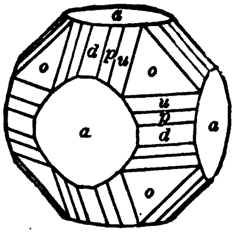

p(221), *u*(554)

Cleavage: cubic, highly perfect; less often octahedral. Fracture flat subconchoidal or even. H. = 2·5–2·75. G. = 7·4–7·6. Luster metallic. Color and streak pure lead-gray. Opaque.

Comp. — Lead sulphide, PbS = Sulphur 13·4, lead 86·6 = 100. Often contains silver, and occasionally selenium, zinc, cadmium, antimony, bismuth, copper, as sulphides; besides, also, sometimes native silver and gold.

Var. — 1. *Ordinary.* (*a*) Crystallized; (*b*) somewhat fibrous and plumose; (*c*) cleavable, granular coarse or fine; (*d*) crypto-crystalline. The variety with octahedral cleavage is rare; in it the usual cubic cleavage is obtained readily after heating to 200° or 300°; the peculiar cleavage may be connected with the bismuth usually present. One variety showing octahedral cleavage contained a small amount of tellurium.

2. *Argentiferous.* All galena is more or less argentiferous, and no external characters serve to distinguish the kinds that are much so from those that are not. The silver is detected by cupellation, and may amount from a few thousandths of one per cent to one per cent or more; when mined for silver it ranks as a *silver ore.*

3. Containing arsenic, or antimony, or a compound of these metals, as impurity. Here belong *bleischweif* from Claustal, Harz Mts., with 0·22 Sb, and *steinmannite* from Přibram, Bohemia, with both arsenic and antimony.

Pyr. — In the open tube gives sulphurous fumes. B.B. on charcoal fuses, emits sulphurous fumes, coats the coal yellow near the assay (PbO) and white with a bluish border at a distance ($PbSO_4$, chiefly), and yields a globule of metallic lead. Decomposed by strong nitric acid with the separation of some sulphur and the formation of lead sulphate.

Diff. — Distinguished, except in very fine granular varieties, by its cubic cleavage; the color and the high specific gravity are characteristic; also the blowpipe reactions.

Micro. — In polished section shows white color with smooth surface usually showing triangular pits. With HNO_3 blackens; with $FeCl_3$ becomes bright, iridescent.

Artif. — Crystallized galena has been formed in numerous ways. In nature it is apparently commonly formed by hydrochemical reactions perhaps similar to the following laboratory methods: galena was produced by allowing a mixture of lead chloride, sodium bicarbonate and a solution of hydrogen sulphide to remain in a sealed tube for several months.

Pyrite or marcasite heated with a solution of lead chloride will produce galena; a solution of lead nitrate when heated with ammonium sulphydrate will yield galena. Galena is frequently observed in furnace slags.

Obs. — One of the most widely distributed of the metallic sulphides. Occurs in beds and veins, both in crystalline and uncrystalline rocks. Very commonly found together with zinc ores in connection with limestone rocks. It is often associated with pyrite, marcasite, sphalerite, chalcopyrite, arsenopyrite, etc., in a gangue of quartz, calcite, barite or fluorite, etc.; also with cerussite, anglesite, and other salts of lead, which are frequent results of its alteration. It is also common with gold, and in veins of silver ores.

A few of the notable localities at which galena has been found are as follows:

At Freiberg in Saxony in veins in gneiss; at Claustal and Neudorf, etc., in the Harz Mts., and at Přibram in Bohemia, it forms veins in clay slate; similarly in Styria; in limestone at Bleiberg, Carinthia; in Silesia, Prussia; at Gonderbach near Laasphe, Westphalia; at Schemnitz, Kapnik, etc., Hungary; Joachimstal, Bohemia; at Poullaouen and Huelgoet, Brittany, France; in Moresnet district in Belgium; in province of Cagliari, Sardinia; in Spain, in granite at Linares, also in Catalonia, Grenada, and elsewhere; in veins through the graywacke of Leadhill, Scotland, and the contact hornstones of Cornwall; filling cavities in the limestone of Derbyshire, Cumberland, and the northern districts of England, associated with calcite, dolomite, fluorite, barite, witherite, calamine and sphalerite; in many places in Australia, Chile, Bolivia, Peru, etc.

Extensive deposits of this ore in the United States exist in Missouri, Illinois, Iowa, and Wisconsin. The ore occurs usually filling cavities or chambers in stratified limestone, of different periods, from Silurian to Carboniferous. It is associated with sphalerite, smithsonite, calcite, pyrite, etc. The Missouri mines are situated in three districts in the southern part of the state, (1) Southeastern, chiefly in St. Francis, Washington and Madison counties, (2) Central, (3) Southwestern or Joplin district, the latter producing chiefly zinc. Other districts in the upper Mississippi Valley are found in southwestern Wis., eastern Iowa and northwestern Ill. Also occurs in N. Y., at Rossie, St. Lawrence Co., in crystals with calcite and chalcopyrite; in Pa., at Phœnixville and elsewhere. In Col., at Leadville and Aspen, there are productive mines of argentiferous galena, also at Georgetown, the San Juan district and elsewhere. Mined for silver in the Cœur d'Alene region in Idaho; at the Park City and Tintic districts in Utah.

The name galena is from the Latin *galena* (γαλήνη), a name given to lead ore or the dross from melted lead.

Use. — The most important ore of lead and frequently a valuable ore of silver.

Cuproplumbite. A massive mineral, from Chile, varying in characters from galena to those of chalcocite and covellite; composition, $Cu_2S.2PbS$(?). Material classed here from Butte, Mon., gave formula, $5Cu_2S.PbS$. *Alisonite* is massive, deep indigo-blue quickly tarnishing; corresponds to $3Cu_2S.PbS$. From Mina Grande, Chile. Whether these and similar minerals represent definite homogeneous compounds, or only ill-defined alteration-products, is uncertain, and if so it is not clear whether they should be classed with isometric galena or with orthorhombic chalcocite.

Altaite. Lead telluride, PbTe. Rarely in cubic or octahedral crystals, usually massive with cubic cleavage. G. = 8·16. Color tin-white, with yellowish tinge tarnishing to bronze-yellow. From the Altai Mts., with hessite; Coquimbo, Chile; Cal., Col., British Columbia.

Clausthalite. Lead selenide, PbSe. Commonly in fine granular masses resembling galena. Cleavage: cubic. G. = 7·6–8·8. Color lead-gray, somewhat bluish. From Claustal, Harz Mts., Germany; Cacheuta mine, Mendoza River, Argentina. *Tilkerodite* is a cobaltiferous variety.

Naumannite. — Silver-lead telluride $(Ag_2,Pb)Se$. In cubic crystals; also massive, granular, in thin plates. Cleavage: cubic. G. = 8·0. Color and streak iron-black. From Tilkerode in the Harz Mts , Germany.

ARGENTITE. Silver Glance.

Isometric. Crystals often octahedral, also cubic; often distorted, frequently grouped in reticulated or arborescent forms; also filiform. Massive; embedded; as a coating.

Cleavage: $a(100)$, $d(110)$ in traces. Fracture small subconchoidal. Perfectly sectile. H. = 2–2·5. G. = 7·20–7·36. Luster metallic. Color and streak blackish lead-gray; streak shining. Opaque.

Comp. — Silver sulphide, Ag_2S = Sulphur 12·9, silver 87·1 = 100.

Pyr., etc. In the open tube gives off sulphurous fumes. B.B. on charcoal fuses with intumescence in O.F., emitting sulphurous fumes, and yielding a globule of silver.

Diff. — Distinguished from other sulphides by being readily cut with a knife; also by yielding metallic silver on charcoal.

Micro. — In polished section shows grayish white color with a smooth surface which is easily scratched. Turns brown with HNO_3,KCN and $FeCl_3$; with conc. HCl tarnished iridescent by fumes and blackened by acid.

Artif. — Argentite is very easily prepared artificially and in numerous ways. Sulphur, sulphur dioxide or hydrogen sulphide will act upon metallic silver or any of its common compounds, either in solution or as solids, to produce silver sulphide.

Obs. — Found at Freiberg, etc., Saxony; Andreasberg, Harz Mts., Germany; Schemnitz, Hungary: Joachimstal, Bohemia; Kongsberg, Norway; Sardinia. In South America at silver mines in Chile, Peru and Bolivia. In Mexico in the states of Chihuahua, Guanajuato, etc. Important ore at Comstock Lode, Tonapah, etc., Nev.; Aspen, Leadville, etc. Col. Found at Port Arthur on north shore of Lake Superior.

Use. — An important ore of silver.

JALPAITE is a cupriferous argentite from Jalpa, Mexico.

Hessite. — Silver telluride, Ag_2Te. Isometric. Usually massive, compact or fine-grained. Cleavage indistinct. Somewhat sectile. H. = 2·5–3. G. = 8·31–8·45. Color between lead-gray and steel-gray. From the Altai Mts.; at Nagyág, Bótes and Rézbánya in Transylvania; Chile near Arqueros, Coquimbo. In Mexico at San Sebastian, Jalisco. In the United States, Calaveras Co., Cal.; Boulder Co., Col.; Utah. This species also often contains gold and thus graduates toward petzite.

Petzite. — $(Ag,Au)_2Te$ with Ag : Au = 3 : 1. Massive; granular to compact. Slightly sectile to brittle. H. = 2·5–3. G. = 8·7–9·02. Color steel-gray to iron-black; tarnishing. From Nagyág, Transylvania; Kalgoorlie, West Australia; Yale District, British Columbia; Col.; Poverty Hill, Tuolumne Co., and elsewhere, Cal.

Aguilarite. Silver selenide, Ag_2S and $Ag_2(S,Se)$. In skeleton dodecahedral crystals. Sectile. G. = 7·586. Color iron-black. From Guanajuato, Mexico.

Berzelianite. Copper selenide, Cu_2Se. In thin dendritic crusts and disseminated. G. = 6·71. Color silver-white, tarnishing. From Skrikerum, Sweden; Lehrbach, in the Harz Mts., Germany.

Lehrbachite. Selenide of lead amd mercury, PbSe with HgSe. Massive, granular. G. = 7·8. Color lead-gray to iron-black. From Lehrbach, in the Harz Mts., Germany.

Eucairite. $Cu_2Se.Ag_2Se$. Massive, granular. G. = 7·50. Color between silver-white and lead-gray. From the Skirkerum copper mine, Sweden; also Chile.

Zorgite. — Selenide of lead and copper in varying amounts. Perhaps a mixture. Massive, granular. G. = 7–7·5. Color dark or light lead-gray. From the Harz Mts., Germany; Cacheuta, Argentina.

Crookesite. Selenide of copper and thallium, also silver (1–5 p. c.), $(Cu,Tl,Ag)_2Se$. Massive, compact. G. = 6·9. Luster metallic. Color lead-gray. From the mine of Skirkerum, Sweden.

Umangite. $CuSe.Cu_2Se$. Massive, fine-granular to compact. H. = 3. G. = 5·620. Color dark cherry-red. From La Rioja, Argentina.

2. *Chalcocite Group*

		a : b : c
Chalcocite	Cu_2S	0·5822 : 1 : 0·9701
Stromeyerite	$Ag_2S.Cu_2S$	0·5822 : 1 : 0.9668
Sternbergite	$Ag_2S.Fe_4S_5$	0·5832 : 1 : 0.8391
Frieseite		0·5970 : 1 : 0·7352
Acanthite	Ag_2S	0·6886 : 1 : 0·9944

The species of the CHALCOCITE GROUP crystallize in the orthorhombic system with a prismatic angle approximating to 60°; they are hence pseudo-hexagonal in form, especially when twinned. The group is parallel to the Galena Group, since Cu_2S appears in isometric form in cuproplumbite and Ag_2S also in argentite. Some authors include dyscrasite here (see p. 361).

CHALCOCITE. Copper Glance. Redruthite.

Orthorhombic. Axes $a : b : c = 0{\cdot}5822 : 1 : 0{\cdot}9701$.

mm''', $110 \wedge 1\bar{1}0 = 60° 25'$. cp, $001 \wedge 111 = 62° 35\tfrac{1}{2}'$.
dd'; $(021) \wedge 0\bar{2}1 = 125° 28'$. pp''', $111 \wedge 1\bar{1}1 = 53° 3\tfrac{1}{2}'$.

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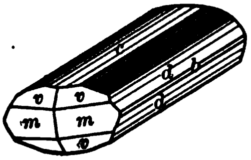

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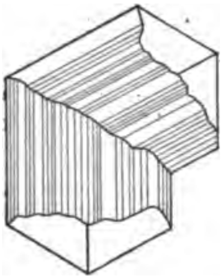

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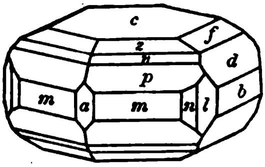

Crystals pseudo-hexagonal in angle, also by twinning (tw. pl. $m(110)$). Often massive, structure granular to compact and impalpable.

Cleavage: $m(110)$ indistinct; etching of orientated crystals develops cleavages parallel to the three pinacoids. Fracture conchoidal. Rather sectile. H. = 2·5–3. G. = 5·5–5·8. Luster metallic. Color and streak blackish lead-gray, often tarnished blue or green, dull. Opaque.

Comp. — Cuprous sulphide, Cu_2S = Sulphur 20·2, copper 79·8 = 100. Sometimes iron in small amount is present, also silver.

Pyr., etc. — In the open tube gives sulphurous fumes. B.B. on charcoal melts to a globule, which boils with spirting; the fine powder roasted at a low temperature on charcoal, then heated in R.F., yields a globule of metallic copper. Soluble in nitric acid.

Diff. — Resembles argentite but much more brittle; bornite has a different color on the fresh fracture and becomes magnetic B.B.

Micro. — In polished section shows grayish or bluish white color with smooth surface. With HNO_3 effervesces and etches, turning more or less blue, and develops cleavage directions; with KCN blackens and etches.

Artif. — Chalcocite has been prepared artificially by heating the vapors of cuprous chloride and hydrogen sulphide or by the treatment of cupric oxide with hydrogen sulphide; also by the heating of cupric solutions with ammonium sulphocyanate in a sealed tube.

Obs. — Chalcocite is an important ore of copper. It is usually secondary in its origin, being found in the upper, enriched portions of copper veins. It is commonly associated with chalcopyrite, bornite, pyrite, cuprite, malachite, azurite, etc.

Cornwall affords splendid crystals, especially the districts of Saint Just, Camborne, and Redruth (*redruthite*). Occurs at Joachimstal, Bohemia; Tellemarken, Norway; compact and massive varieties in Siberia; Saxony; Mte. Catini mines in Tuscany; Mexico; South America.

In the United States, Bristol, Conn., has afforded large and brilliant crystals; also found at Simsbury and Cheshire; at Schuyler's mines, N. J.; in Nev., in Washoe, Humboldt, Churchill and Nye counties; at Clifton, Ariz.; in Mon., massive at Butte in great amounts. Notable deposit at Kennecott, Copper River District, Alaska. Found in Canada, with chalcopyrite and bornite at the Acton mines and elsewhere in the province of Quebec.

Use. — An important ore of copper.

Stromeyerite. $(Ag,Cu)_2S$, or $Ag_2S.Cu_2S$. Rarely in orthorhombic crystals, often twinned. Commonly massive, compact. H. = 2·5–3. G. = 6·15–6·3. Luster metallic. Color and streak dark steel-gray. From the Zmeinogorsk mine, Siberia; Silesia; also Chile, Zacatecas, Mexico; Cobalt, Ontario; the Heintzelman mine in Ariz.; Col.

Chalmersite. $Cu_2S.Fe_4S_5$. Orthorhombic. Axial ratio near that of chalcocite. In thin elongated prisms vertically striated. Twins common with $m(110)$ as tw. pl. resembling chalcocite. H. = 3·5. G. = 4·7. Color brass- to bronze-yellow. Strongly magnetic. From the Morro Velho gold mine, Minas Geraes, Brazil.

STERNBERGITE

Orthorhombic. Crystals tabular || *c*(001). Commonly in fan-like aggregations; twins, tw. pl. *m*(110). Cleavage : *c*(001), highly perfect. Thin laminæ flexible, like tin-foil. H. = 1–1·5. G. = 4·215. Luster metallic. Color pinchbeck-brown. Streak black. Opaque.

Comp. — $AgFe_2S_3$ or $Ag_2S.Fe_4S_5$ = Sulphur 30.4, silver 34.2, iron 35.4 = 100.

Obs. — Occurs with pyrargyrite and stephanite at Joachimstal, Bohemia, and Johanngeorgenstadt, Saxony.

FRIESEITE. Near sternbergite. In thick tabular crystals. H. = 2·5; G. = 4·22. Color dark gray. Composition $Ag_2Fe_5S_8$. Occurs with marcasite at Joachimstal, Bohemia.

Acanthite. Silver sulphide, Ag_2S, like argentite. In slender prismatic crystals (orthorhombic). Sectile. G. = 7·2–7·3. Color iron-black. Occurs at Joachimstal, Bohemia; also at Freiberg and Schneeberg, Saxony; at Rico, Col.

It has been suggested that acanthite may be only argentite in distorted isometric crystals.

Sphalerite Group. RS. Isometric-tetrahedral

Sphalerite	ZnS	**Onofrite**	Hg(S,Se)	
Metacinnabarite	HgS	**Alabandite**	MnS	
Guadalcazarite	(Hg,Zn)S	**Coloradoite**	HgTe	Massive
Tiemannite	HgSe			

The SPHALERITE GROUP embraces a number of sulphides, selenides, etc., of zinc, mercury, and manganese. These are isometric-tetrahedral in crystallization.

SPHALERITE, ZINC BLENDE or BLENDE. Black-Jack, Mock-Lead, False Galena.

Isometric-tetrahedral. Often in tetrahedrons. Twins common: tw. pl. *o*(111); twinning often repeated, sometimes as polysynthetic lamellæ. Commonly massive cleavable, coarse to fine granular and compact; also foliated, sometimes fibrous and radiated or plumose; also botryoidal and other imitative shapes. Cryptocrystalline to amorphous, the latter sometimes as a powder.

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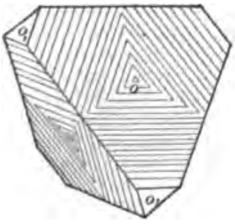

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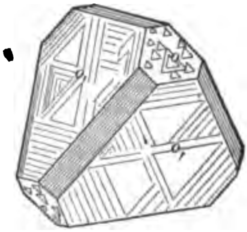

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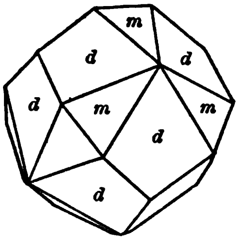

m = (311)

Cleavage: dodecahedral, highly perfect. Fracture conchoidal. Brittle. H. = 3·5–4. G. = 3·9–4·1; 4·063 white, N. J. Luster resinous to adamantine. Color commonly yellow, brown, black; also red, green to white, and when pure nearly colorless. Streak brownish to light yellow and white. Transparent to translucent. Refractive index high: *n* = 2·3692.

Comp. — Zinc sulphide, ZnS = Sulphur 33, zinc 67 = 100. Often containing iron and manganese, and sometimes cadmium, mercury and rarely lead and tin. Also sometimes contains traces of indium, gallium and thallium; may be argentiferous and auriferous.

Var. — 1. *Ordinary.* Containing little or no iron; from colorless white to yellowish brown, sometimes green; G. = 4·0–4·1. The red or reddish brown transparent crystallized kinds are sometimes called *ruby blende* or *ruby zinc*. The massive cleavable forms are the most common, varying from coarse to fine granular; also cryptocrystalline. *Schalenblende* is a closely compact variety, of a pale liver-brown color, in concentric layers with reniform surface; galena and marcasite are often interstratified. The fibrous forms are chiefly wurtzite. A soft white amorphous form of zinc sulphide occurs in Cherokee Co., Kan.

2. *Ferriferous: Marmatite.* Containing 10 p. c. or more of iron; dark-brown to black; G. = 3·9–4·05. The proportion of FeS to ZnS varies from 1 : 5 to 1 : 2, and the last ratio is that of the *christophite* of Breithaupt, a brilliant black sphalerite from St. Christophe mine, at Breitenbrunn, having G. = 3·91–3·923.

3. *Cadmiferous: Pribramite, Przibramite.* The amount of cadmium present in any sphalerite thus far analyzed is less than 5 per cent.

Pyr., etc. — Difficultly fusible. In the open tube sulphurous fumes, and generally changes color. B.B. on charcoal, in R.F., gives a coating of zinc oxide, which is yellow while hot and white after cooling. If cadmium is present a reddish brown coating of cadmium oxide will form first. With cobalt solution the zinc oxide coating gives a green color when heated in O.F. Most varieties, after roasting, give with borax a reaction for iron. Dissolves in hydrochloric acid with evolution of hydrogen sulphide.

Diff. — Varies widely in color and appearance, but distinguished by the resinous luster in all but deep black varieties; usually exhibits distinct cleavage; nearly infusible B.B.; yields a zinc oxide coating on charcoal.

Micro. — In polished section shows a gray color with smooth surface. Transparent, yellow to brown with oblique illumination. With HNO_3 becomes slowly brown, often showing crystal structure; with aqua regia effervesces and blackens.

Artif. — Sphalerite has been artificially formed by heating zinc solutions in hydrogen sulphide inclosed in a sealed tube; also by passing hydrogen sulphide over heated zinc chloride.

Obs. — Sphalerite is the most important ore of zinc. It occurs in both crystalline and sedimentary rocks, being especially common in the limestones, where it often occurs as beds of considerable size. It is frequently associated with galena, also with chalcopyrite, pyrite, barite, fluorite, siderite, etc. Commonly found with silver ores. Of the two forms of zinc sulphide, sphalerite is the form which crystallizes below 1020° while wurtzite is deposited at higher temperatures. Zinc sulphide is deposited from alkaline solutions as sphalerite; from acid solutions both forms are deposited, the amount of sphalerite increasing with the temperature while that of wurtzite increases with the acidity of the solution.

Some of the chief localities for crystallized sphalerite are: Alston Moor in Cumberland and at St. Agnes and elsewhere in Cornwall, England; Andreasberg and Neudorf in the Harz Mts., Freiberg, and other localities in Saxony; Přibram, and Schlackenwald in Bohemia; Kapnik, Schemnitz and Felsöbánya, in Hungary; Nagyág and Rodna in Transylvania; the Binnental in Switzerland, isolated crystals of great beauty, yellow to brown, in cavities of dolomite. A beautiful transparent variety yielding large cleavage masses is brought from Picos de Europa, Santander, Spain, where it occurs in a brown limestone. A similar variety with golden brown to green colors from Chivera mine, Cannanea, Mexico. Large crystals from Ani copper mines, Ugo, Japan. Fibrous varieties (see wurtzite) are obtained at Přibram; Geroldseck in Baden; Raibl, Carinthia; also in Cornwall. The original *marmatite* is from Marmato near Popayan, Italy.

The important zinc ore districts of the United States in which sphalerite is the chief zinc mineral are found in Missouri, Colorado, Montana, Wisconsin, Idaho and Kansas. Some localities noteworthy for the specimens they have produced are as follows: In Conn., at Roxbury. In N. J., a *white* variety (*cleiophane*) at Franklin Furance. In Pa., at the Wheatley and Perkiomen lead mines, in crystals; near Friedensville, Lehigh Co., a grayish waxy variety. In Ill., near Rosiclare, with galena and calcite; at Marsden' diggings, near Galena, in stalacites, with crystallized marcasite, and galena; at Warsaw. In Wis., at Mineral Point, in fine crystals. In Ohio, at Tiffin. In Mo., in beautiful crystallizations with galena, marcasite and calcite at Joplin and other points in the southwestern part of the state; the deposits here occur in limestone and are of great extent and value; also in adjoining parts of Kan. In Col., at many places.

Named *blende* because, while often resembling galena, it yielded no lead, the word in German meaning *blind* or *deceiving*. *Sphalerite* is from *σφαλερός*, *treacherous*.

Use. — The most important ore of zinc.

Metacinnabarite. Mercuric sulphide, HgS. In composition like cinnabar, but occurs in *black* tetrahedral crystals; also massive. G. = 7·7. In Cal., from the Reddington mine, Lake county, with cinnabar, quartz and marcasite; and from San Joaquin, Orange Co. Found also at Idria in Austria.

Guadalcazarite. Near metacinnabarite, but contains zinc (up to 4 p. c.). Guadalcazar, Mexico. Probably a mixture.

Tiemannite. Mercuric selenide, HgSe. Isometric-tetrahedral. Commonly massive; compact. G. = 8·19 Utah; 8·30–8·47 Claustal. Luster metallic. Color steel-gray to blackish lead-gray. Streak nearly black. Occurs at Claustal in the Harz Mts.; Cal., in the vicinity of Clear lake; Marysvale, Piute Co., Utah.

Onofrite. Hg(S,Se) with Se = 4·5 to 6·5 p. c. San Onofre, Mexico; Marysvale, Utah.

Coloradoite. Mercuric telluride, HgTe. Massive. Conchoidal fracture. H. = 2·5. G. = 8·07 (Kalgoorlie). Color iron-black. Originally found sparingly in Colorado. Rather abundant at the Kalgoorlie district, West Australia. Material called *kalgoorlite* is a mixture of coloradoite and petzite.

Alabandite. Manganese sulphide, MnS. Isometric-tetrahedral; usually granular massive. Cleavage: cubic, perfect. G. = 3·95–4·04. Luster submetallic. Color iron-black. Streak green. Occurs at Nagyág, Transylvania; Kapnik, Hungary; Mexico; Peru; crystallized and massive on Snake River, Summit county, Col.; Tombstone, Ariz.

Oldhamite. Calcium sulphide, CaS. In pale brown spherules with cubic cleavage in the Busti meteorite. Also noted in Allegan meteorite.

PENTLANDITE.

Isometric. Massive, granular. Cleavage: octahedral. Fracture uneven. Brittle. H. = 3·5–4. G. = 5·0. Luster metallic. Color light bronze-yellow. Streak light bronze-brown. Opaque. Not magnetic.

Comp. — A sulphide of iron and nickel, (Fe,Ni)S. In part, 2FeS.NiS = Sulphur 36·0, iron 42·0, nickel 22·0 = 100.

Obs. — Occurs with chalcopyrite near Lillehammer, Norway. Also from Sudbury, Ontario, where it is intimately associated with nickeliferous pyrrhotite. It can be distinguished from the latter by its cleavage.

4. *Cinnabar-Wurtzite-Millerite Group.* Rhombohedral or Hexagonal

			c	
Cinnabar	HgS	Rhombohedral-Trapezohedral	1·1453	
Covellite	CuS		1·1466	
			c	*c*
Greenockite	CdS	Hexagonal-Hemimorphic	0·8109 or	0·9364
Wurtzite	ZnS	"	0·8175	0·9440
Millerite	NiS	Rhombohedral		0·9883
Niccolite	NiAs	"	0·8194	0·9462
Breithauptite	NiSb	"	0·8586	0·9915
Arite	Ni(Sb,As)			
Pyrrhotite	$Fe_{11}S_{12}$, etc.	Hexagonal	0·8701	1·0047
Troilite	FeS			

This fourth group among the monosulphides includes several subdivisions, as shown in the scheme above, and the relations of the species are not in all cases perfectly clear. It is to be noted that the sulphides of mercury and zinc, already represented in the sphalerite group, appear here again.

If, as suggested by Groth, the prominent pyramids of wurtzite, greenockite, etc., be made pyramids of the second series (*e.g.*, $x = 11\bar{2}2$, instead of $10\bar{1}1$), then the values of *c* in the second column are obtained, which correspond to millerite. The form of several of these species, however, is only imperfectly known. A rhombohedral form for greenockite has been suggested.

CINNABAR.

Rhombohedral-trapezohedral. Axis c = 1·1453.

rr', 1011 ∧ $\bar{1}$011 = 87° 23′.
ii', 4045 ∧ $\bar{4}$045 = 78° 0½′.
cr, 0001 ∧ 10$\bar{1}$1 = 52° 54′.

Crystals usually rhombohedral or thick tabular in habit, rarely showing trapezohedral faces; in rhombohedral penetration twins; also acicular prismatic. In crystalline incrustations, granular, massive; sometimes as an earthy coating.

Cleavage: m(10$\bar{1}$0) perfect. Fracture subconchoidal, uneven. Somewhat sectile. H. = 2–2·5. G. = 8·0–8·2. Luster adamantine, inclining to metallic when dark-colored, and to dull in friable varieties. Color cochineal-red, often inclining to brownish red and lead-gray. Streak scarlet. Transparent to opaque. Optically +. Indices: ω_r = 2·82, ϵ_r = 3·14. See Art. 394.

Var. — 1. *Ordinary:* either (*a*) *crystallized;* (*b*) *massive,* granular embedded or compact; bright red to reddish brown in color; (*c*) *earthy* and bright red. 2. *Hepatic.* Of a liver-brown color, with sometimes a brownish streak, occasionally slaty in structure, though commonly granular or compact.

Comp. — Mercuric sulphide, HgS = Sulphur 13·8, mercury 86·2 = 100. Usually impure from the admixture of clay, iron oxide, bitumen.

Pyr. — In the closed tube alone a black sublimate of mercuric sulphide, but with sodium carbonate one of metallic mercury. Carefully heated in the open tube gives sulphurous fumes and metallic mercury, which condenses in minute globules on the cold walls of the tube. B.B. on charcoal wholly volatile, but only when quite free from gangue.

Diff. — Characterized by its color and vermilion streak, high specific gravity (reduced, however, by the gangue usually present), softness; also by the blowpipe characters (*e.g.*, in the closed tube). Resembles some varieties of hematite and cuprite.

Artif. — Cinnabar has been produced artificially by several methods which are, however, in general modifications of the two following types: (1) When the black mercury sulphide formed by the direct union of mercury and sulphur is sublimed, cinnabar is the product; (2) the black sulphide when treated with solutions of alkaline sulphides is converted into cinnabar. In general cinnabar is formed under alkaline conditions and metacinnabarite under acidic conditions.

Obs. — Cinnabar is the only common mineral of mercury and with rare exceptions constitutes the ore of the metal. It occurs in veins filling fissures and cavities in rocks which are commonly sedimentary in character, being often slates, shales, sandstones or limestones. While infrequently occurring in igneous rocks such rocks are commonly near by and are thought to have been the source of the metal. Cinnabar is deposited from hot alkaline solutions or as the result of solfataric action. Pyrite and marcasite, sulphides of copper, stibnite, realgar, gold, etc., are associated minerals; calcite, quartz or opal, also barite, fluorite, are gangue minerals; a bituminous mineral is common.

The most important European deposits are at Almaden in Spain, and at Idria in Carniola, where it is usually massive; also at Bakmut in southern Russia. Crystallized at Moschellandsberg and Wolfstein in the Palatinate and at the mines of Mt. Avala, near Belgrade, Servia; at Ripa in Tuscany; at Alsósajó, Hungary; in the Ural Mts., the Nerchinsk region in Transbaikalia; in large twinned rhombohedrons from Province of Kweichow, China; Japan; Mexico; Huancavelica, Peru; Chile.

In the United States forms extensive mines in Cal., the most important at New Almaden and the vicinity, in Santa Clara Co.; also at Altoona, Trinity Co.; it is now forming by solfataric action at Sulphur Bank, Cal., and Steamboat Springs, Nev.; has been found in southern Utah; important deposits occur in Brewster Co., Texas; also mined in Nev. and Ariz.

The name cinnabar is supposed to come from India, where it is applied to the red resin, dragon's blood. The native cinnabar of Theophrastus is true cinnabar; he speaks of its affording quicksilver. The Latin name of cinnabar, *minium*, is now given to *red lead*, a substance which was early used for adulterating cinnabar, and so got at last the name.

Only comparatively few localities have furnished the mineral in quantity.

Use. — The most important ore of mercury.

COVELLITE.

Monoclinic? Pseudohexagonal through twinning. Crystals usually thin hexagonal plates. Often massive.

Cleavage: basal, perfect. H. = 1·5–2. G. = 4·6. Luster submetallic to resinous. Color indigo-blue or darker. Often shows fine purple color when moistened with water. Streak lead-gray to black. Opaque.

Comp. — Cupric sulphide, CuS = Sulphur 33·6, copper 66·4 = 100.

Pyr., etc. — Fusible at 2·5 yielding sulphurous fumes. After roasting and moistening with hydrochloric acid gives azure-blue flame. Much sulphur in C.T.

Micro. — In polished section shows blue color with smooth surface. With KCN becomes instantly deep violet which rubs off, leaving a yellow coating and rough surface.

Artif. — Covellite has been prepared artificially by heating in sealed tubes a cupric solution with ammonium sulphocyanate and by heating sphalerite in a solution of copper sulphate.

Obs. — Covellite is a mineral of secondary origin found in the enriched portions of copper sulphide veins, associated with chalcocite, bornite, etc. Found in small amounts in many places. Noteworthy localities are as follows: various places in Germany; in exceptional crystals at Bor in Timoker Kreis, Servia; on the lavas of Vesuvius; in Chile; Province of Rikuchu, Japan. In the United States at the Butte district, Mon.; Summitville, Col.; La Sal district, Utah; Kennecott, Alaska, etc.

GREENOCKITE.

Hexagonal-hemimorphic. Rarely in hemimorphic crystals; also as a coating.

Cleavage: $a(11\bar{2}0)$ distinct, $c(0001)$ imperfect. Fracture conchoidal. Brittle. H. = 3–3·5. G. = 4·9–5·0. Luster adamantine to resinous. Color honey-, citron-, or orange-yellow. Streak between orange-yellow and brick-red. Nearly transparent. Optically +. $\omega = 2{\cdot}506, \epsilon = 2{\cdot}529$.

Comp. — Cadmium sulphide, CdS = Sulphur 22·3, cadmium 77·7 = 100.

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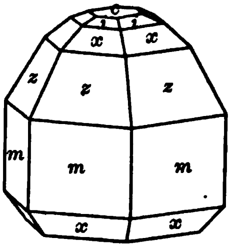

Pyr., etc. — In the closed tube assumes a carmine-red color while hot, fading to the original yellow on cooling. In the open tube gives sulphurous fumes. B.B. on charcoal, either alone or with soda, gives in R.F. a reddish brown coating. Soluble in hydrochloric acid, affording hydrogen sulphide.

Artif. — Greenockite has been prepared artificially in several ways. Precipitated cadmium sulphide when fused with potassium carbonate and sulphur produced greenockite crystals; also when cadmium sulphate, calcium fluoride and barium sulphide were fused together. Greenockite is formed when cadmium oxide is heated in sulphur vapor.

Obs. — Occurs with prehnite at Bishopton, Renfrewshire, and elsewhere in Scotland. At Přibram in Bohemia, as a coating on sphalerite; similarly at other points; so too in the United States near Friedensville, Pa., and in the zinc region of southwestern Mo.; in Marion Co., Ark., it colors smithsonite bright yellow; noted at Franklin, N. J. Not uncommon as a furnace product.

Use. — An ore of cadmium.

Wurtzite. Zinc sulphide, ZnS, like sphalerite, but in hemimorphic hexagonal crystals; also fibrous and massive. G. = 3·98. Color brownish black. See under sphalerite, p. 368, for the conditions of its formation. From a silver-mine near Oruro in Bolivia; Portugal; at Mies, Bohemia; Peru. In crystals with sphalerite and quartz at the "Original Butte" mine, Butte, Mon. In crystals from Joplin, Mo.; from near Frisco, Beaver Co., Utah.

The massive fibrous forms of "Schalenblende" occur at Přibram, Bohemia; Liskeard, Cornwall, etc. Other forms, from Stolberg, Wiesloch, Altenberg, Germany, are in part wurtzite, in part sphalerite.

MILLERITE. Capillary Pyrites.

Rhombohedral. Usually in very slender to capillary crystals, often in delicate radiating groups; sometimes interwoven like a wad of hair. Also in columnar tufted coatings, partly semi-globular and radiated. The rhombohedron $(01\bar{1}2)$ is a gliding plane and artificial twins may be formed.

Cleavage perfect parallel to $(10\bar{1}1)$ and $(01\bar{1}2)$. Fracture uneven. Brittle; capillary crystals elastic. H. = 3–3·5. G. = 5·3–5·65. Luster metallic. Color brass-yellow, inclining to bronze-yellow, with often a gray iridescent tarnish. Streak greenish black.

Comp. — Nickel sulphide, NiS = Sulphur 35·3, nickel 64·7 = 100.

Pyr., etc. In the open tube sulphurous fumes. B.B. on charcoal fuses to a globule. When roasted, gives with borax and salt of phosphorus a violet bead in O.F., becoming gray in R.F. from reduced metallic nickel. On charcoal in R.F. the roasted mineral gives a coherent metallic mass, attractable by the magnet. Most varieties also show traces of copper, cobalt, and iron with the fluxes.

Artif. — Crystals of millerite have been formed artificially by treating under pressure a solution of nickel sulphate with hydrogen sulphide.

Obs. — Found at Joachimstal and Příbram in Bohemia; in Germany at Johanngeorgenstadt and Freiberg, Saxony; Wissen, Prussia; in Cornwall, England.

In the United States, at Antwerp, N. Y., in cavities in hematite; in Lancaster Co., Pa., at the Gap mine, in thin velvety coatings of a radiated fibrous structure. With calcite, dolomite and fluorite, forming delicate tangled hair-like tufts, in geodes in limestone, often penetrating the calcite crystals, at St. Louis, Mo.; similarly near Milwaukee, Wis. At Orford, Quebec.

Use. — An ore of nickel.

BEYRICHITE. NiS like millerite, but with lower specific gravity (4·7). Laspeyres considers all millerite as formed by paramorphism from beyrichite. Found in Westerwald, Rhine-Prussia.

HAUCHECORNITE. Perhaps Ni(Bi,Sb,S). In tabular tetragonal crystals. H. = 5. G. = 6·4. Color light bronze-yellow. From Hamm a. d. Sieg, Germany.

NICCOLITE. Copper Nickel.

Hexagonal. Crystals rare. Usually massive, structure nearly impalpable; also reniform, columnar; reticulated, arborescent. Fracture uneven. Brittle. H. = 5–5·5. G. = 7·33–7·67. Luster metallic. Color pale copper-red. Streak pale brownish black. Opaque.

Comp. — Nickel arsenide, NiAs = Arsenic 56·1, nickel 43·9 = 100. Usually contains a little iron and cobalt, also sulphur; sometimes part of the arsenic is replaced by antimony, and then it graduates toward breithauptite. The intermediate varieties have been called *arite*.

Pyr., etc. — In the closed tube on intense ignition gives a faint sublimate of arsenic. In the open tube a sublimate of arsenic trioxide, with a trace of sulphurous fumes, the assay becoming yellowish green. On charcoal gives arsenical fumes and fuses to a globule, which, treated with borax glass, affords, by successive oxidation, reactions for iron, cobalt, and nickel; the antimonial varieties give also reactions for antimony. Soluble in aqua regia.

Obs. — Accompanies cobalt, silver and copper ores in Germany in the Saxon mines of Annaberg, Schneeberg, Mansfield, etc.; also in Thuringia, Hesse, and in Styria; at Allemont, Dauphiné, at Balen in the Basses Pyrenées, France (*arite*); at the Ko mines in Nordmark, Sweden; occasionally in Cornwall, Chile; abundant at Mina de la Rioja, Oriocha, Argentina. In the United States, sparingly at Franklin Furnace, N. J., Silver Cliff, Col. In Canada, at Cobalt, Ontario.

Use. — An ore of nickel.

TEMISKAMITE. Described as having composition Ni_4As_3, has been shown to be a mixture of *niccolite*, *maucherite* and a little *cobaltite*.

Breithauptite. Nickel antimonide, NiSb. Rarely in hexagonal crystals; usually massive, arborescent, disseminated. G. = 7·54. Color light copper-red. From Andreasberg in the Harz Mts., Germany.

PYRRHOTITE. Magnetic Pyrites.

Hexagonal. $c = 0{\cdot}8701$.

cs, $0001 \wedge 10\bar{1}1 = 45° \ 8'$.
cu, $0001 \wedge 40\bar{4}1 = 76° \ 0'$.
cy, $0001 \wedge (20{\cdot}0{\cdot}\overline{20}{\cdot}3) = 81° \ 30\tfrac{1}{2}'$.

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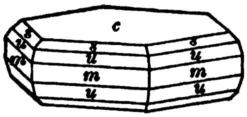

Twins: tw. pl. $s(10\bar{1}1)$, with vertical axes nearly at right angles (Fig. 418, p. 167). Distinct crystals rare, commonly tabular; also acute pyramidal with faces striated horizontally. Usually massive, with granular structure.

Parting: $c(0001)$, sometimes distinct. Fracture uneven to subconchoidal. Brittle. H. = 3·5–4·5. G. = 4·58–4·64. Luster metallic. Color between bronze-yellow and copper-red, and subject to speedy tarnish. Streak dark grayish black. Magnetic, but varying much in intensity; sometimes possessing polarity.

Comp. — Ferrous sulphide containing variable amounts of dissolved sulphur. Analyses show variation from Fe_5S_6 to $Fe_{16}S_{17}$. Often also contains nickel. Fe_7S_8 = Sulphur 39·6, iron 60·4 = 100. (Cf. Art. **473**, p. 323.)

Pyrrhotite differs from troilite in containing more or less of dissolved sulphur, while troilite, occurring in meteorites where there is always an excess of iron, may form the pure monosulphide.

Pyr., etc. — Unchanged in the closed tube. In the open tube gives sulphurous fumes. On charcoal in R.F. fuses to a black magnetic mass; in O.F. is converted into red oxide, which with fluxes gives only an iron reaction when pure, but many varieties yield small amounts of nickel and cobalt. Decomposed by hydrochloric acid, with evolution of hydrogen sulphide.

Diff. — Distinguished by its peculiar reddish bronze color; also by its magnetic properties.

Micro. — In polished section shows a cream color with a shiny and pitted surface. With hot HCl tarnishes quickly, giving bright colors, then blackens and dissolves; with aqua regia effervesces, becomes iridescent in center of drop and brown at the edge.

Artif. — Pyrrhotite has been synthesized by the direct union of iron and sulphur and also when pyrite is heated in an atmosphere of hydrogen sulphide at 550°. Pyrrhotite exists in two crystalline modifications, hexagonal at ordinary temperatures and orthorhombic above 138°.

Obs. — Occurs at Kongsberg, Modum, Kristiania, etc., in Norway; Falun, Sweden; Andreasberg in the Harz Mts., Germany; Schneeberg, Saxony; Leoben and Lavantal, Carinthia; Minas Geraes in Brazil, in large tabular crystals; the lavas of Vesuvius; Cornwall.

In North America, in Me., at Standish with andalusite; in Ver., at Stafford, etc. In N. Y., near Diana, Lewis Co.; Orange Co.; at Tilly Foster mine, Brewsters. In Pa., at the Gap mine, Lancaster Co., nickeliferous. In Tenn., at Ducktown mines, abundant. In Canada, in large veins at St. Jérôme, Elizabethtown, Ontario; large deposit mined for nickel at Sudbury, Ontario.

Named from *πυρρότης, reddish*.

Use. — Often becomes a valuable ore of nickel.

Troilite. Ferrous sulphide, FeS, occurring in nodular masses and in thin veins in many iron meteorites. G. = 4·75–4·82. Color tombac-brown. Considered to be the end member of the pyrrhotite series. See above.

C. Intermediate Division

Polydymite. A nickel sulphide, perhaps Ni_4S_5. In octahedral crystals; frequently twinned. G. = 4·54–4·81. Color gray. From Grünau, Westphalia, Germany.

Sychnodymite. Essentially $(Co,Cu)_4S_5$. Isometric, in small steel-gray octahedrons. From the Siegen district, Germany.

The following species are sometimes regarded as Sulpho-salts, namely, Sulpho-ferrites, etc.

BORNITE. Peacock Ore. Purple Copper Ore. Variegated Copper Ore. Erubescite.

Isometric. Habit cubic, faces often rough or curved. Twins: tw. pl. *o*(111), often penetration-twins. Crystals rare. Usually massive, structure granular or compact.

Cleavage: *o* (111), in traces. Fracture small conchoidal, uneven. Brittle. H. = 3. G. = 4·9–5·4. Luster metallic. Color between copper-red and pinchbeck-brown on fresh fracture, speedily iridescent from tarnish. Streak pale grayish black. Opaque.

Comp. — A sulphide of copper and iron. Cu_5FeS_4. Copper 63·3, iron 11·1, sulphur 25·6 = 100.

The mineral often contains small amounts of chalcocite, etc., and therefore shows considerable variation in its percentage composition, giving from 50 to 70 p. c. of copper and 15 to 6·5 p. c. of iron.

Pyr., etc. — In the closed tube gives a faint sublimate of sulphur. In the open tube yields sulphurous fumes. B.B. on charcoal fuses in R.F. to a brittle magnetic globule. The roasted mineral gives with the fluxes the reactions of iron and copper, and with soda a metallic globule. Soluble in nitric acid with separation of sulphur.

Diff. — Distinguished (*e.g.*, from chalcocite) by the peculiar reddish color on the fresh fracture and by its brilliant tarnish; B.B. becomes strongly magnetic.

Micro. — In polished section shows a pinkish brown color with smooth surface. With HNO_3 becomes quickly golden-brown with effervescence.

Artif. — Bornite has been obtained by fusing pyrite, copper and sulphur together; by heating a mixture of cuprous, cupric and ferric oxides in hydrogen sulphide at 100° to 200°.

Obs. — Bornite is often a primary mineral of magmatic origin, being frequently found in igneous rocks. It is also often a secondary mineral, occurring with chalcocite, etc., in the enriched portions of copper sulphide veins. It is usually associated with other copper ores, and is a valuable ore of copper. Crystalline varieties are found in Cornwall, called by the miners "horse-flesh ore." Occurs massive at Ross Island, Killarney, Ireland; Monte Catini, Tuscany; the Mansfeld district, Germany; in Norway, Sweden, Siberia, Silesia, and Hungary. It is the principal copper ore at some Chilian mines; also common in Peru, Bolivia, and Mexico.

In the United States, found at the copper mine in Bristol, Conn.; massive at Mahoopeny, near Wilkesbarre, Pa.; in western Idaho; Butte, Mon., etc. A common ore in Canada, at the Acton and other mines.

Named after the mineralogist Ignatius von Born (1742–1791).

Use. — An ore of copper.

Linnæite. A sulphide of cobalt, $Co_3S_4 = CoS.Co_2S_3$, analogous to the spinel group. Also contains nickel (var. *siegenite*). Commonly in octahedrons; also massive. H. = 5·5. G. = 4·8–5. Color pale steel-gray, tarnishing copper-red. Occurs at Bastnaes, etc., Sweden; Müsen, near Siegen, Prussia; at Siegen (*siegenite*), in octahedrons. In the United States at Mine la Motte, Mo.; Mineral Hill, Md.

Daubréelite. An iron-chromium sulphide, $FeS.Cr_2S_3$, occurring with troilite in some meteoric irons. Color black. G. = 5·01.

CUBANITE. Described as an iron-copper sulphide, perhaps $CuFe_2S_4 = CuS.Fe_2S_3$. Examination of specimens from several localities show it to be a mixture of pyrite or pyrrhotite with chalcopyrite.

CARROLITE. A copper-cobalt sulphide, $CuCo_2S_4 = CuS.Co_2S_3$. Isometric; rarely in octahedrons. Usually massive. G. = 4·85. Color light steel-gray, with a faint reddish hue. From Carroll Co., Md., near Finksburg. Probably linnæite with intergrown bornite and chalcopyrite.

Badenite. $(Co,Ni,Fe)_2(As,Bi)_3$. Massive granular to fibrous. G. = 7·1. Metallic. Color steel-gray. Fusible. From near Badeni-Ungureni, Neguletzul valley, Roumania.

CHALCOPYRITE. Copper Pyrites. Yellow Copper Ore.

Tetragonal-sphenoidal. Axis *c* = 0·98525.

pp', 111 ∧ $\bar{1}\bar{1}1$ = 108° 40'. *pp,,* 111 ∧ $1\bar{1}1$ = 70° 7½'. *ce*, 001 ∧ 101 = 44° 34½'.

Crystals commonly tetrahedral in aspect, the sphenoidal faces *p*(111) large, dull or oxidized; *p*,(1$\bar{1}$1) small and brilliant. Sometimes both forms equally developed, and then octahedral in form. Twins: (1) tw. pl. *p*(111), resembling spinel-twins (Fig. 417, p. 167); sometimes repeated as a fiveling (Fig. 655). (2) Tw. pl. and comp.-face *e*(101) (Fig. 656,) often in repeated twins. (3) Tw. pl. *m*(110), tw. axis *c*, complementary penetration twins. Often massive, compact.

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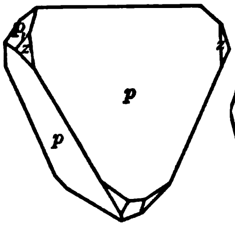

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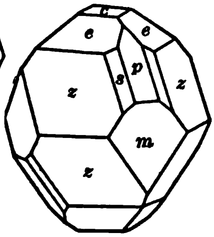

z(201), *s*(513)

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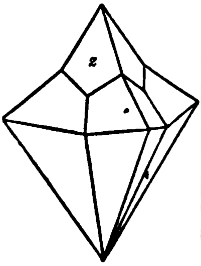

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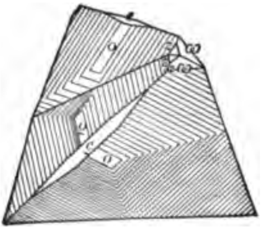


Cleavage: *z*(201), sometimes distinct; *c*(001), indistinct. Fracture uneven. Brittle. H. = 3·5–4. G. = 4·1–4·3. Luster metallic. Color brass-yellow; often tarnished or iridescent. Streak greenish black. Opaque.

Comp. — A sulphide of copper and iron, $CuFeS_2$ = Sulphur 35·0, copper 34·5, iron 30·5 = 100. Analyses often show variations from this formula, often due to mechanical admixture of pyrite.

Sometimes auriferious and argentiferous; also contains traces of selenium and thallium.

Pyr., etc.— In the closed tube often decrepitates, and gives a sulphur sublimate, in the open tube sulphurous fumes. On charcoal fuses to a magnetic globule; the residue moistened with hydrochloric acid and then touched with blowpipe flame gives intense blue flame color. Decomposed by nitric acid giving free sulphur and a green solution; ammonia in excess changes the green color to a deep blue, and precipitates red ferric hydroxide.

Diff. — Distinguished from pyrite by its inferior hardness and deeper yellow color. Resembles gold when disseminated in minute grains in quartz, but differs in being brittle and in having a black streak; further it is soluble in nitric acid.

Micro. — In polished section shows a bright brass-yellow color with smooth surface. With hot HNO_3 tarnishes and dissolves. Unaffected by KCN, differing from gold.

Artif. — Chalcopyrite has been artificially prepared (1) by fusing pyrite and copper sulphide together; (2) by gently heating cupric and ferric oxides in an atmosphere of hydrogen sulphide.

Obs. — Chalcopyrite is the most common and important mineral containing copper. It is commonly of primary origin and from it, by various alteration processes, many other copper minerals are derived. It has repeatedly been observed as an original constituent of igneous rocks and the ultimate source of the copper of our ore deposits is to be found in rocks of this type. It occurs widely disseminated in metallic veins and nests in gneiss and crystalline schists, also in serpentine rocks; often intimately associated with pyrite, also with siderite, tetrahedrite, etc., sometimes with nickel and cobalt sulphides, pyrrhotite, etc. Observed coated with tetrahedrite crystals in parallel position, also as a coating over the latter. Frequently associated with sphalerite, its crystals often lying with parallel orientation upon the latter mineral.

Chalcopyrite is so widely distributed as an ore mineral that it is possible to mention here only those occurrences which are exceptional either because of their size or because of the quality of the minerals found in them.

It is the principal ore of copper at the Cornwall mines; there associated with cassiterite, galena, bornite, chalcocite, tetrahedrite, sphalerite. At Falun, Sweden, it occurs in large masses embedded in gneiss. At Rammelsberg, near Goslar in the Harz Mts., Germany, it forms a bed in argillaceous schist; occurs with nickel and cobalt ores in the Kupferschiefer of Mansfield. In Germany the Kurprinz mine at Freiberg affords well-defined crystals; also Horhausen, Dillenburg, Neudorf, Müsen. Common elsewhere as at Mte. Catini in Tuscany; Rio Tinto, Spain; in New South Wales; Chile; Japan, etc.

In the United States it is found in large crystals associated with quartz at Ellenville, N. Y.; in exceptional crystals at the French Creek mines, Chester Co., Pa., associated with pyrite, magnetite, etc.; in Mo., with sphalerite at Joplin; at various localities in Gilpin and other counties in Col. The most important sulphide deposits of copper in many of which chalcopyrite is the chief ore are found in the states of Arizona, Montana, Utah, Alaska, Nevada, New Mexico, California, and Tennessee.

In Canada there are important copper deposits in British Columbia, Ontario and Quebec,

Use. — The most important ore of copper.

Named from χαλκός, *brass*, and *pyrites*, by Henckel (1725).

D. Disulphides, Diarsenides, etc.

The disulphides, diarsenides, etc., embrace two distinct groups. The prominent metals included are the same in both, viz.: iron, cobalt and nickel. The groups present, therefore, several cases of isodimorphism, as is shown in the lists of species below. These sulphides are all relatively *hard*, H. = 5–6; they hence strike fire with a steel, and this has given the familiar name *pyrites* applied to most of them. The color varies between pale brass-yellow and tin-white.

Pyrite Group. RS_2,RAs_2,RSb_2. Isometric-pyritohedral

Pyrite	FeS_2	**Gersdorffite**	$NiS_2.NiAs_2$
Arsenoferrite	$FeAs_2$	**Corynite**	$NiS_2.Ni(As,Sb)_2$
Cobaltnickelpyrite	$(Co,Ni,Fe)S_2$	**Ullmannite**	$NiS_2.NiSb_2$ (isometric-tetartohedral)
Hauerite	MnS_2		
Smaltite	$CoAs_2$, also $(Co,Ni)As_2$	**Sperrylite**	$PtAs_2$
Chloanthite	$NiAs_2$, also $(Ni,Co)As_2$	**Laurite**	RuS_2?
Cobaltite	$CoS_2.CoAs_2$		

Marcasite Group. RS_2, RAS_2, etc. Orthorhombic

		$a : b : c$	$110 \wedge 1\bar{1}0$	$101 \wedge \bar{1}01$
Marcasite	FeS_2	0·7662 : 1 : 1·2342	74° 55′	116° 20′
Löllingite	$FeAs_2$	0·6689 : 1 : 1·2331	67° 33′	123° 3′
Leucopyrite	$Fe_3 As_4$			
Arsenopyrite	$FeS_2.FeAs_2$	0·6773 : 1 : 1·1882	68° 13′	120° 38′
Danaite	$(Fe,Co)S_2.(Fe,Co)As_2$			
Safflorite	$CoAs_2$			
Rammelsbergite	$NiAs_2$			
Glaucodot	$(Co,Fe)S_2.(Co,Fe)As_2$	0·6942 : 1 : 1·1925	69° 32′	119° 35′
Alloclasite	$(Co,Fe)(As,Bi)S$			
Wolfachite	$NiS_2.Ni(As,Sb)_2$			

The PYRITE GROUP includes, besides the compounds of Fe, Co, Ni, also others of the related metals Mn and Pt. The crystallization is isometric-pyritohedral.

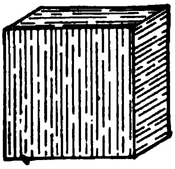
The species of the MARCASITE GROUP crystallize in the orthorhombic system with prismatic angles of about 70° and 110° and a prominent macrodome of about 60° and 120°. Hence fivefold and sixfold repeated twins are common with several species, in the one case the prism and in the other the macrodome named being the twinning-plane.

Pyrite Group

PYRITE. Iron Pyrites.

Isometric-pyritohedral. Cube and pyritohedron *e*(210) the common forms, the faces of both often with striations || edge *a*(100)/*e*(210), due to oscillatory combination of these forms and tending to produce rounded faces; pyritohedral faces also striated ⊥ to this edge; octahedron also common. See Figs. 657–662, also Figs. 133–138, pp. 65, 66. Twins: tw. ax. = a crystal axis, usually penetration-twins with parallel axes (Fig. 407, p. 166); rarely contact-twins. Frequently massive, fine granular; sometimes subfibrous radiated; reniform, globular, stalactitic.

657



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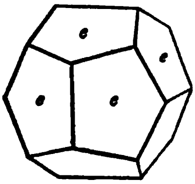

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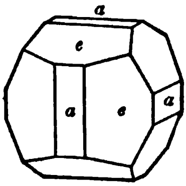

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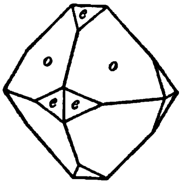

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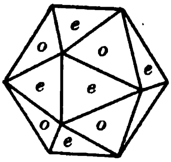

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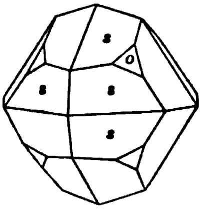


Cleavage: *a*(100), *o*(111), indistinct. Fracture conchoidal to uneven. Brittle. H. = 6–6·5. G. = 4·95–5·10; 4·967 Traversella, 5·027 Elba. Luster metallic, splendent to glistening. Color a pale brass-yellow, nearly uniform. Streak greenish black or brownish black. Opaque.

Comp. — Iron disulphide, FeS_2 = Sulphur 53·4, iron 46·6 = 100.

Nickel, cobalt, and thallium, and also copper in small quantities, sometimes replace part of the iron, or else occur as mixtures; selenium is sometimes present in traces. Gold is sometimes distributed invisibly through it, auriferous pyrite being an important source of gold. Arsenic is rarely present, as in octahedral crystals from French Creek, Pa. (0·2 p. c. As).

Pyr., etc. — Easily fusible, (2·5–3). Becomes magnetic on heating and yields sulphur dioxide. Gives an abundant sublimate of sulphur in the closed tube. Insoluble in hydrochloric acid. The fine powder is completely soluble in strong nitric acid.

Diff. — Distinguished from chalcopyrite by its greater hardness and paler color; in form and specific gravity different from marcasite, which has also a whiter color.

Micro. — In polished section shows a cream color with a scratched and dull surface. With HNO_3 effervesces slowly becoming faintly brown.

Alteration. — Pyrite readily changes by oxidation to an iron sulphate or to the hydrated oxide, limonite, with sulphuric acid set free. Crystals of pyrite which have been changed on their surfaces to limonite are common. This change may continue until the original mineral has completely disappeared. Large masses of pyrite lying near the surface may be altered to a cellular mass of limonite — the *iron gossan* of the miners — while the sulphuric acid set free travels downward and enters into various important reactions with the unaltered minerals below. The alteration of pyrite to limonite may be continued until hematite is formed.

Obs. — Experiments show that pyrite is formed in neutral or alkaline solutions and at high temperatures. Marcasite, on the other hand, is deposited from acid solutions and is stable only at temperatures below 450° C. These sulphides can be formed through the action of hydrogen sulphide, although the reducing action of carbonaceous materials may also at times be of importance. Pyrite occurs in rocks of all ages and types, being most common in the metamorphic and sedimentary rocks, but it is also frequently found as a minor accessory constituent of igneous rocks. When disseminated in the rocks it usually occurs in small crystals, cubes, octahedrons, pyritohedrons, etc., but in veins it may occur in crystals or with a granular or radiating massive structure. At times it is in nodular or concretionary forms.

Pyrite is very widespread in its occurrence, being the most common sulphide mineral. At times it is found in very large amounts and is mined for its sulphur content or because it contains small amounts of some valuable metal, like copper, gold, etc. It is frequently found in crystals with a fine luster. Some of the more notable localities for its occurrence are given below.

Important commercial deposits of pyrite are found in Norway, Germany, France, Italy, Spain and Portugal. The mines at Rio Tinto, Spain, are especially noteworthy. The mineral has been mined in the United States in Louisa and Prince William Cos., Va.; in St. Lawrence Co., N. Y.; at Davis, Mass., etc. The following localities furnish exceptionally fine crystallized specimens: Cornwall, England; Traversella and Brosso, Piedmont Italy; Island of Elba; Ardennes, France, in distorted cubes; Minden, Prussia, in interpenetration twins; in various localities in Bohemia, Hungary, Germany, Sweden, etc.; at Firmeza, Cuba; at French Creek, Pa., in pyramids with apparently tetragonal or orthorhombic symmetry; at Rossie and Scoharie, N. Y.; Roxbury, Conn.; Franklin, N. J.; Gilpin Co. and at Leadville, Col.; Bingham Canyon, Utah.

The name pyrite is derived from πυρ, *fire*, and alludes to the sparks formed when the mineral is struck with a hammer; hence the early name *pyrites*, p. 376.

Use. — Pyrite often carries small amounts of copper or gold and becomes an important ore of these metals. It is also mined for its sulphur content which is used in the form of sulphur dioxide (used in the preparation of wood pulp for manufacture into paper), as sulphuric acid (used for many purposes, especially in the purification of kerosene and in the preparation of mineral fertilizers), and as the ferrous sulphate, copperas (used in dyeing, in inks, as a wood preservative, and as a disinfectant).

Bravoite $(Fe,Ni)S_2$. Contains nearly 20 per cent nickel. In small grains and crystal fragments, apparently octahedral. Pale yellow with a faint reddish tarnish. Occurs disseminated through the vanadium ores at Minasragra, Peru.

Cobaltnickelpyrite.[1] Iron sulphide with about 20 per cent cobalt and nickel, $(Co,Ni,Fe)S_2$. In minute pyritohedral crystals. Steel-gray color. Gray-black streak. H. = 5. G. = 4·716. Found at Müsen, Germany.

Arsenoferrite. Iron arsenide, probably $FeAs_2$. Isometric-pyritohedral. In small crystals. Color dark brown. Fine splinters transparent with ruby-red color. From the Binnental, Switzerland.

Hauerite. — Manganese disulphide, MnS_2. In octahedral or pyritohedral crystals; also massive. G. = 3·46. Color reddish brown or brownish black. From Kalinka, Hungary; Raddusa, Catania, Sicily.

SMALTITE-CHLOANTHITE.

Isometric-pyritohedral. Commonly massive; in reticulated and other imitative shapes.

Cleavage: *o*(111) distinct; *a*(100) in traces. Fracture granular and uneven. Brittle. H. = 5·5–6. G. = 6·4 to 6·6. Luster metallic. Color tin-white, inclining, when massive, to steel-gray, sometimes iridescent, or grayish from tarnish. Streak grayish black. Opaque.

Comp. — SMALTITE is essentially cobalt diarsenide, $CoAs_2$ = Arsenic 71·8, cobalt 28·2 = 100. CHLOANTHITE is nickel diarsenide, $NiAs_2$ = Arsenic 71·9, nickel 28·1 = 100.

Cobalt and nickel are usually both present, and thus these two species graduate into each other, and no sharp line can be drawn between them. Iron is also present in varying amount; the variety of chloanthite containing much iron has been called *chathamite*. Further sulphur is usually present, but only in small quantities. Many analyses do not conform even approximately to the formula RAs_2, the ratio rising from less than 1 : 2 to 1 : 2·5 and nearly 1 : 3, thus showing a tendency toward skutterudite (RAs_3), perhaps due to either molecular or mechanical mixture. Microscopic examination of polished specimens shows probable zoning of different members of the group. Material known as *keweenawite* is a mixture of smaltite, niccolite and domeykite.

Much that has been called smaltite is shown by the high specific gravity to belong to the orthorhombic species safflorite.

Pyr., etc. — In the closed tube gives a sublimate of metallic arsenic; in the open tube a white sublimate of arsenic trioxide, and sometimes traces of sulphur dioxide. B.B. on charcoal gives a coating of As_2O_3, the arsenical odor, and fuses to a globule, which, treated with successive portions of borax-glass, affords reactions for iron, cobalt, and nickel.

Obs. — Usually occurs in veins, accompanying ores of cobalt or nickel, and ores of silver and copper; also, in some instances, with niccolite and arsenopyrite. Found at the Saxon mines; Joachimstal, Bohemia; Wheal Sparnon, Cornwall; Riechelsdorf, Hesse, Germany; Tunaberg, Sweden; Allemont, Dauphiné, France; Cobalt, Ontario. In the United States, at Chatham, Conn., the *chathamite* occurs in mica slate, with arsenopyrite and niccolite; at Franklin Furnace, N. J.

Use. — Ores of cobalt and nickel.

COBALTITE.

Isometric-pyrithohedral. Commonly in cubes, or pyritohedrons, or combinations resembling common forms of pyrite. Also granular massive to compact.

Cleavage: cubic, rather perfect. Fracture uneven. Brittle. H. = 5·5. G. = 6–6·3. Luster metallic. Color silver-white, inclined to red; also steel-gray, with a violet tinge, or grayish black when containing much iron. Streak grayish black.

Comp. — Sulpharsenide of cobalt, $CoAsS$ or $CoS_2.CoAs_2$ = Sulphur 19·3, arsenic 45·2, cobalt 35·5 = 100.

Iron is present, and in the variety *ferrocobaltite* in large amount.

Pyr., etc. — Unaltered in the closed tube. In the open tube gives sulphurous fumes, and a crystalline sublimate of arsenic trioxide. B.B. on charcoal gives off sulphur and arsenic oxides, and fuses to a magnetic globule; with borax a cobalt-blue color. Soluble in warm nitric acid, with the separation of sulphur.

Obs. — Occurs at Tunaberg and Hakansbö in Sweden; at the Nordmark mines; also at Skutterud in Norway; at Schladming, Styria; Siegen in Westphalia; Botallack mine, near St. Just, in Cornwall; Khetri mines, Rajputana, India; Cobalt, Ontario, Canada.

Use. — An ore of cobalt.

Gersdorffite. Sulpharsenide of nickel, $NiAsS$ or $NiS_2.NiAs_2$. Iron, and sometimes cobalt, replace more or less of the nickel. Isometric-pyritohedral; usually massive. H. = 5·5. G. = 5·6–6·2. Color silver-white to steel-gray. From Loos, Sweden; the Harz Mts., and Lobenstein, Reuss-Schleiz, Germany; Schladming, Styria; Sudbury and Algoma districts, Ontario; Rossland, British Columbia.

CORYNITE is near gersdorffite, but contains also antimony. Probably represents a mixture. From Olsa, Carinthia.

Willyamite. — $CoS_2.NiS_2.CoSb_2.NiSb_2$. Cleavage cubic. Color tin-white to steel-gray. Broken Hill mines, New South Wales.

Villamaninite. Sulphide of Cu,Ni with smaller amounts of Co,Fe. H = 4·5. G. = 4·4–4·5. Color, iron-black. In irregular groups of cubo-octahedral crystals and in radiating nodular masses. In dolomite from Cármenes district, near Villamanín, Prov. Léon, Spain.

Ullmannite. Sulphantimonide of nickel, $NiSbS$ or $NiS_2.NiSb_2$; arsenic is usually present in small amount. Isometric-tetartohedral; both pyritohedral and tetrahedral forms occur. Usually massive, granular. H. = 5–5·5. G. = 6·2–6·7. Color steel-gray to silver-white. Occurs in the mines of Siegen, Prussia; Lölling, Carinthia (tetrahedral); Monte Narba, Sarrabus, Sardinia (pyritohedral).

KALLILITE. $Ni(Sb,Bi)S$ or $NiS_2.Ni(Sb,Bi)_2$. Massive, color light bluish gray. From the Friedrich mine near Schönstein a. d. Sieg, Germany.

Sperrylite. — Platinum diarsenide, $PtAs_2$. In minute cubes, or cubo-octahedrons with at times small pyritohedral or diploid faces. H. = 6–7. G. = 10·6. Luster metallic. Color tin-white. Streak black. Found at the Vermillion mine, 22 miles west of Sudbury, Ontario, Canada; also in Macon Co., N. C. Found associated with covellite at the Rambler mine, Medicine Bow Mts., Wy. This is the only known native compound of platinum.

Laurite. Sulphide of ruthenium and osmium, probably essentially RuS_2. In minute octahedrons; in grains. H. = 7·5. G. = 6·99. Luster metallic. Color dark iron-black. From the platinum washings of Borneo. Also reported from Oregon.

Skutterudite. Cobalt arsenide, $CoAs_3$. Isometric-pyritohedral. Also massive granular. Cleavage: *a*(100), distinct. H. = 6. G. = 6·72–6·86. Color between tin-white and pale lead-gray. From Skutterud, Norway; the Turtmanntal, Switzerland.

NICKEL-SKUTTERUDITE. $(Ni,Co,Fe)As_3$. Massive, granular. Color gray. From near Silver City, N. M.

BISMUTO-SMALTITE. $Co(As,Bi)_3$. A skutterudite containing bismuth. Color tin-white. G. = 6·92. Zschorlau, near Schneeberg, Saxony.

Marcasite Group

For the list of species and their relations, see p. 376.

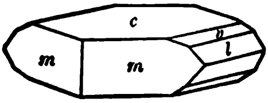
MARCASITE. White iron pyrites.

Orthorhombic. Axes $a : b : c = 0{\cdot}7662 : 1 : 1{\cdot}2342$.

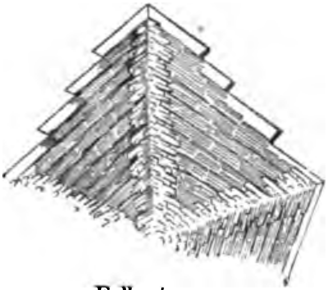
mm''', 110 ∧ $1\bar{1}0$ = 74° 55'. *ll'*, 011 ∧ $0\bar{1}1$ = 101° 58'.
ee', 101 ∧ $\bar{1}01$ = 116° 20'. *cs*, 001 ∧ 111 = 63° 46'.

Twins: tw. pl. *m*(110), sometimes in stellate fivelings (Fig. 436, p. 169, cf. Fig. 664); also tw. pl. *e*(101), less common, the crystals crossing at angles of nearly 60°. Crystals commonly tabular || *c*(001), also pyramidal; the brachydomes striated || edge *b*(010)/*c*(001). Often massive; in stalactites; also globular, reniform, and other imitative shapes. Cleavage: *m*(110) rather distinct; *l*(011) in traces. Fracture uneven. Brittle. H. = 6–6·5. G = 4·85–4·90. Luster metallic. Color pale bronze-yellow, deepening on exposure. Streak grayish or brownish black. Opaque.

663



664



Folkestone

Comp. — Iron disulphide, like pyrite, FeS_2 = Sulphur 53·4, iron 46·6 = 100. Arsenic is sometimes present in small amount.

Var. — The varieties named depend mainly on state of crystallization. *Radiated:* Radiated; also the simple crystals. *Cockscomb Pyrite:* Aggregations of flattened twin crystals in crest-like forms. *Spear Pyrite:* Twin crystals, with re-entering angles a little like the head of a spear in form. (Fig. 664.) *Capillary:* In capillary crystallizations.

Pyr., etc. — Like pyrite. Very liable to decomposition, more so than pyrite.

Diff. — Resembles pyrite, but has a lower specific gravity, and the color when fresh (*e.g.*, after treatment with acid) is paler; when crystallized easily distinguished by the forms. More subject to tarnish and final decomposition than pyrite.

Marcasite can be distinguished chemically from pyrite by the following methods. When both minerals are finely powdered and treated with a little concentrated nitric acid, first in the cold and later, after vigorous action has ceased, by warming, it will be found that in the case of pyrite the greater part of the sulphur of the mineral has been oxidized and taken into solution as sulphuric acid, while in the case of marcasite most of the sulphur has separated in a free state. The Stokes method, which can be used quantitatively to determine the amounts of the two minerals in a mixture, depends upon the difference in their behavior when boiled with a standard solution of ferric sulphate. In the case of pyrite about 52 per cent of the sulphur is oxidized to sulphuric acid, while with marcasite only about 12 per cent is oxidized.

Micro. — In polished sections shows a cream color with a scratched and dull surface. With HNO_3 slowly turns brown to black with effervescence.

Alteration. — Marcasite being relatively unstable is easily altered. Specimens often disintegrate with the formation of ferrous sulphate and sulphuric acid. It also alters to pyrite, limonite, etc.

Obs. — Marcasite is a much more unstable compound than pyrite and is formed under comparatively limited conditions. Experiments have shown that it is deposited at temperatures below 450° C. and in acid solutions. The higher the temperature the more acid must the solution contain. At ordinary temperatures marcasite may be deposited from nearly neutral solutions. Marcasite is formed in general under surface conditions, while in deep veins where the minerals are deposited from ascending hot and usually alkaline waters only pyrite is found.

Marcasite occurs abundantly at Littmitz near Carlsbad, Bohemia. Found at several localities in the Harz Mts., Germany. In its cockscomb form occurs at Tavistock in Devonshire and as Spear Pyrites in the chalk-marl between Folkestone and Dover, England. In the United States a notable locality is at Galena, Ill., where it occurs in stalactites with concentric layers of sphalerite and galena. In fine crystals at Mineral Point, Wis.; in crystals altered to limonite from Richland Co., Wis. Frequently associated with galena, sphalerite and dolomite from the Joplin district, Mo.

The word *marcasite*, of Arabic or Moorish origin (and variously used by old writers, for bismuth, antimony), was the name of common crystallized pyrite among miners and mineralogists in later centuries, until near the close of the eighteenth. It was first given to this species by Haidinger in 1845.

Löllingite. Essentially iron diarsenide, $FeAs_2$, but passing into Fe_3As_4 (*leucopyrite*); also tending toward arsenopyrite (FeAsS) and safflorite ($CoAs_2$). Bismuth and antimony are sometimes present. Usually massive. H. = 5–5·5. G. = 7·0–7·4 chiefly, also 6·8. Luster metallic. Color between silver-white and steel-gray. Streak grayish black. Occurs in the Lölling-Hüttenberg district in Carinthia. Found also sparingly in a number of other districts.

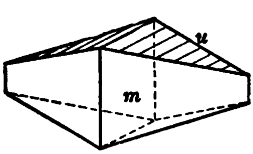
GEYERITE is near löllingite, but contains sulphur; from Geyer, Saxony.

ARSENOPYRITE, or MISPICKEL.

Orthorhombic. Axes $a : b : c = 0{\cdot}6773 : 1 : 1{\cdot}1882$.

mm''', $110 \wedge 110 = 68^\circ\ 13'$.
ee', $101 \wedge \bar{1}01 = 120^\circ\ 38'$.
uu', $014 \wedge 0\bar{1}4 = 33^\circ\ 5'$.
nn', $012 \wedge 0\bar{1}2 = 61^\circ\ 26'$.
qq', $011 \wedge 0\bar{1}1 = 99^\circ\ 50'$.

665



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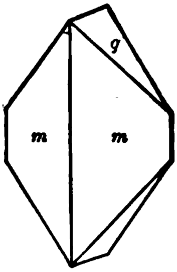

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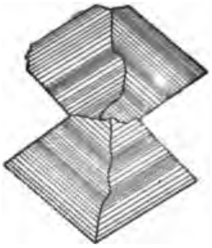

Twins: tw. pl. *m*(110), sometimes repeated like marcasite (Figs. 667 and 437, p. 109); *e*(101) cruciform twins, also trillings (Figs. 432, 433, p. 169). Crystals prismatic *m*(110) or flattened vertically by the oscillatory combination of brachydomes. Also columnar, straight, and divergent; granular, or compact.

Cleavage: *m*(110) rather distinct; *c*(001) in faint traces. Fracture uneven. Brittle. H. = 5·5–6. G. = 5·9–6·2. Luster metallic. Color silver-white, inclining to steel-gray. Streak dark grayish black. Opaque.

Comp. — Sulpharsenide of iron, FeAsS or $FeS_2.FeAs_2$ = Arsenic 46·0, sulphur 19·7, iron 34·3 = 100. Part of the iron is sometimes replaced by cobalt, as in the variety *danaite* (3 to 9 p. c. Co).

Pyr., etc. — In the closed tube may give at first a little yellow sulphide of arsenic and then a conspicuous sublimate of metallic arsenic which is of bright gray crystals near the heated end and of a brilliant black amorphous deposit farther away. In the open tube gives sulphurous fumes and a white sublimate of arsenic trioxide. B.B. on charcoal gives arsenical fumes and a magnetic globule. Decomposed by nitric acid with the separation of sulphur.

Diff. — Characterized by its hardness and tin-white color; closely resembles some of the sulphides and arsenides of cobalt and nickel, but identified, in most cases easily, by its blowpipe characters. Löllingite does not give a decided sulphur reaction.

Micro. — In polished sections shows a white color with scratched and dull surface. With HNO$_3$ darkens quickly through iridescent colors to brown, showing rough surface.

Obs. — Found principally in crystalline rocks, its usual mineral associates being ores of silver, lead, and tin, also pyrite, chalcopyrite, and sphalerite. Abundant at Freiberg, etc., in Saxony; at Andreasberg, Harz Mts., Germany; Sala, Sweden; Skutterud, Norway; at several points in Cornwall. In crystals in the Binnental, Switzerland. Crystals of *danaite* from Sulitjelma, Finland.

In the United States, in N. H., in gneiss, at Franconia (*danaite*). In Conn., at Mine Hill, Roxbury, with siderite. In crystals at Canton, Ga.; Leadville, Col. In twin crystals in quartz ore veins at Deloro, Hastings Co., Ontario.

The name mispickel is an old German term of doubtful origin. *Danaite* is from J. Freeman Dana of Boston (1793–1827), who made known the Franconia locality.

Use. — An ore of arsenic.

Safflorite. Like smaltite, essentially cobalt diarsenide, CoAs$_2$. Form near that of arsenopyrite. Usually massive. H. = 4·5–5. G. = 6·9–7·3. Color tin-white, soon tarnishing. From Germany at Schneeberg, Saxony; Bieber, Hesse; Wittichen, Baden; from Tunaberg, Sweden.

Rammelsbergite. Essentially nickel diarsenide, NiAs$_2$, like chloanthite. Crystals resembling arsenopyrite; also massive. G. = 6·9–7·2. Color tin-white with tinge of red. Occurs at Schneeberg, Saxony, and at Riechelsdorf, Hesse, Germany.

Glaucodot. Sulpharsenide of cobalt and iron, (Co,Fe)AsS. In orthorhombic crystals (axes, etc., p. 376). Also massive. H. = 5. G. = 5·90–6·01. Luster metallic. Color grayish tin-white. Occurs in the province of Huasco, Chile; at Hakansbö, Sweden. Named from γλαυκός, *blue*, because used for making smalt.

ALLOCLASITE. Probably glaucodot containing bismuth and other impurities. Commonly in columnar to hemispherical aggregates. H. = 4·5. G. = 6·6. Color steel-gray. From Orawitza, Hungary.

Wolfachite. Probably Ni(As,Sb)S, near corynite. In small crystals resembling arsenopyrite; also columnar radiated. H. = 4·5–5. G. = 6·372. Color silver-white to tin-white. From Wolfach, Baden, Germany.

Melonite. A nickel telluride, NiTe$_2$. In indistinct granular and foliated particles. Color reddish white, with metallic luster. From the Stanislaus mine, Cal.; probably also in Boulder Co., Col. Found at Worturpa, New South Wales.

The following species are tellurides of gold, silver, etc.

SYLVANITE. Graphic Tellurium.

Monoclinic. $a : b : c = 1·6339 : 1 : 1·1265$; $\beta = 89° 35'$. Often in branching arborescent forms resembling written characters; also bladed and imperfectly columnar to granular.

Cleavage: *b*(010) perfect. Fracture uneven. Brittle. H. = 1·5–2. G. = 7·9–8·3. Luster metallic, brilliant. Color and streak pure steel-gray to silver-white, inclining to yellow.

Comp. — Telluride of gold and silver (Au,Ag)Te$_2$ with Au : Ag = 1 : 1; this requires: Tellurium 62·1, gold 24·5, silver 13·4 = 100.

Pyr., etc. — When a little of the powdered mineral is heated in concentrated sulphuric acid a reddish violet color is given to the solution. When treated with nitric acid is decomposed leaving residue of rusty colored gold. A few drops of hydrochloric acid added to this solution yield an abundant precipitate of silver chloride. In the open tube gives a white sublimate of tellurium dioxide which near the assay is gray; when treated with the blowpipe flame the sublimate fuses to clear transparent drops. B.B. on charcoal fuses to a dark gray globule, covering the coal with a white coating, which treated in R.F. disappears, giving a bluish green color to the flame; after long blowing a yellow, malleable metallic globule is obtained.

Obs. — With gold, at Offenbánya, Transylvania; also at Nagyág. With calaverite at Kalgoorlie district, West Australia. In Cal., Calaveras Co., at the Melones and Stanislaus mines. In Boulder Co., at Cripple Creek and elsewhere in Col. Named from Transylvania, where first found, and in allusion to *sylvanium*, one of the names at first proposed for the metal tellurium.

Use. — An ore of gold

Krennerite. A telluride of gold and silver $(Au,Ag)Te_2$ like sylvanite. In prismatic crystals (orthorhombic), vertically striated. G. = 8·353. Color silver-white to brass-yellow. From Nagyág, Transylvania; Cripple Creek, Col.

Calaverite. A gold telluride, $AuTe_2$ with small amounts of silver. Monoclinic. In small lath-shaped crystals striated parallel to their length. Massive granular to crystalline. H. = 2·5. G: = 9·043. Color silver-white with often a faint yellow tinge. Tests similar to those for sylvanite with smaller amount of silver showing. Occurs with petzite at the Stanislaus mine, Calaveras county, Cal. An important gold ore at the Cripple Creek district, Col. Found elsewhere in that state. Occurs abundantly at Kalgoorlie, West Australia.

Muthmannite. (Ag,Au)Te. In tabular crystals usually elongated in one direction. One perfect cleavage parallel to elongation. H. = 2·5. Color bright brass-yellow, on fresh fracture gray-white. Probably from Nagyág, Transylvania. *Empressite*, AgTe, from the Empress-Josephine mine, in the Kerber Creek District, Col., is probably a gold-free variety. Massive. H. = 3–3·5. G. = 7·5. Color pale bronze.

Nagyagite. A sulpho-telluride of lead and gold; some analyses show also about 7 p. c. of antimony which was probably due to impurities. Orthorhombic. Crystals tabular ‖ *b*(010); also granular massive, foliated. Cleavage: *b* perfect; flexible. H. = 1–1·5. G. = 6·85–7·2. Luster metallic, splendent. Streak and color blackish lead-gray. Opaque. From Nagyág, Transylvania; and at Offenbánya. Reported from Colorado and Tararu Creek, New Zealand.

Oxysulphides

Here are included Kermesite, Sb_2S_2O, and Voltzite, Zn_5S_4O.

Kermesite. Pyrostibite. Antimony oxysulphide, Sb_2S_2O or $2Sb_2S_3.Sb_2O_3$. Monoclinic. Usually in tufts of capillary crystals. Cleavage: *a*(100) perfect. H. = 1–1·5. G. = 4·5–4·6. Luster adamantine. Color cherry-red.

Results from the alteration of stibnite. Occurs at Malaczka, Hungary; Bräunsdorf, Saxony; Allemont, Dauphiné, France. At South Ham, Wolfe Co., Quebec, Canada; with native antimony and stibnite at the Prince William mine, York Co., New Brunswick.

Named from *kermes*, a name given (from the Persian *qurmizq*, crimson) in the older chemistry to red amorphous antimony trisulphide. often mixed with antimony trioxide.

Voltzite. Zinc oxysulphide, Zn_5S_4O or $4ZnS.ZnO$. In implanted spherical globules. H. = 4–4·5. G. = 3·66–3·80. Color dirty rose-red, yellowish. Occurs near Pontgibaud, Puy-de-Dôme, France; Joachimstal, Bohemia; Marienberg, Saxony, Germany.

III. SULPHO-SALTS

I. Sulpharsenites, Sulphantimonites, Sulphobismuthites.

II. Sulpharsenates, Sulphostannates, etc.

I. Sulpharsenites, Sulphantimonites, etc.

In these sulpho-salts, as further explained on p. 320, sulphur takes the place of the oxygen in the commoner and better understood oxygen acids (as carbonic acid, H_2CO_3, sulphuric acid, H_4SO_4, phosphoric acid, H_3PO_4, etc.).

The species included are salts of the sulpho-acids of trivalent *arsenic*, *antimony* and *bismuth*. The most important acids are the ortho-acids,

H_3AsS_3, etc., and the meta-acids, H_2AsS_2, etc.; but $H_4As_2S_5$, etc., and a series of others are included. The metals present as bases are chiefly *copper*, *silver*, *lead;* also *zinc*, *mercury*, *iron*, rarely others (as *nickel*, *cobalt*) in small amount. In view of the hypothetical character of many of the acids whose salts are here represented, there is a certain advantage, for the sake of comparison, in writing the composition after the dualistic method, $RS.As_2S_3$, $2RS.As_2S_3$, etc.

As a large part of the species here included are rare and hence to be mentioned but briefly, the classification can be only partially developed. The divisions under the first and more important section of sulpharsenites, etc., with the prominent species under each, are as follows:

A. Acidic Division. $RS : (As,Sb,Bi)_2S_3 = 1 : 3, 1 : 2, 2 : 3, 3 : 4, 4 : 5$.

B. Meta- Division. $RS : (As,Sb,Bi)_2S_3 = 1 : 1$.
General formula: $RAs_2S_4, RSb_2S_4, RBi_2S_4$.

Zinkenite Group

Zinkenite	$PbS.Sb_2S_3$	**Emplectite**	$Cu_2S.Bi_2S_3$
Sartorite	$PbS.As_2S_3$	**Chalcostibite**	$Cu_2S.Sb_2S_3$, etc.
Also			
Miargyrite	$Ag_2S.Sb_2S_3$	**Lorandite**	$Tl_2S.As_2S_3$

C. Intermediate Division. $RS : (As,Sb,Bi)_2S_3 = 5 : 4, 3 : 2, 2 : 1, 5 : 2$

Here belong

Plagionite	$5PbS.4Sb_2S_3$.		
Schirmerite	$3(Ag_2,Pb)S.2Bi_2S_3$	**Klaprotholite**	$3Cu_2S.2Bi_2S_3$, etc.

Jamesonite Group

Jamesonite	$2PbS.Sb_2S_3$	**Cosalite**	$2PbS.Bi_2S_3$, etc.
Dufrenoysite	$2PbS.As_2S_3$		
Also **Freieslebenite**	$5(Ag_2,Pb)S.2Sb_2S_3$	**Boulangerite**	$5PbS.2Sb_2S_3$

D. Ortho- Division. $RS : (As,Sb,Bi)_2S_3 = 3 : 1$

General formula: $\overset{I}{R}_3AsS_3, \overset{I}{R}_3SbS_3; \overset{II}{R}_3As_2S_6, \overset{II}{R}_3Sb_2S_6$, etc.

Bournonite Group

Bournonite	$3(Cu_2,Pb)S.Sb_2S_3$	**Wittichenite**	$3Cu_2S.Bi_2S_3$
Seligmannite	$3(Cu_2,Pb)S.As_2S_3$	**Lillianite**	$3PbS.Bi_2S_3$, etc.
Aikinite	$3(Pb,Cu_2)S.Bi_2S_3$		

Pyrargyrite Group

Pyrargyrite	$3Ag_2S.Sb_2S_3$	**Proustite**	$3Ag_2S.As_2S_3$

E. Basic Division. $RS : (As,Sb,Bi)_2S_3 = 4 : 1, 5 : 1, 6 : 1, 9 : 1, 12 : 1$

Tetrahedrite Group

Tetrahedrite	$4Cu_2S.Sb_2S_3$	**Tennantite**	$4Cu_2S.As_2S_3$

Jordanite Group

Jordanite	$4PbS.As_2S_3$	**Meneghinite**	$4PbS.Sb_2S_3$
Also			
Geocronite	$5PbS.Sb_2S_3$	**Stephanite**	$5Ag_2S.Sb_2S_3$
Kilbrickenite	$6PbS.Sb_2S_3$	**Beegerite**	$6PbS.Bi_2S_3$

Polybasite Group

Polybasite	$9Ag_2S.Sb_2S_3$	**Pearceite**	$9Ag_2S.As_2S_3$
Polyargyrite	$12Ag_2S.Sb_2S_3$		

A. Acidic Division

Eichbergite. $(Cu,Fe)_2S.3(Bi,Sb)_2S_3$. Color iron-gray. H. > 6. G. = 5·36. From Eichberg, Semmering district, Austria.

Livingstonite. $HgS.2Sb_2S_3$. Resembles stibnite in form. Color lead-gray; streak red. H. = 2. G. = 4·81. From Huitzuco, Mexico.

Histrixite. $5CuFeS_2.2Sb_2S_3.7Bi_2S_3$. Orthorhombic. In radiating groups of prismatic crystals. H. = 2. Color and streak steel-gray. Found at Ringville, Tasmania.

Chiviatite. $2PbS.3Bi_2S_3$. Foliated massive. Color lead-gray. From Chiviato, Peru.

Cuprobismutite. Probably $3Cu_2S.4Bi_2S_3$, in part argentiferous. Resembles bismuthinite. G. = 6·3–6·7. From Hall valley, Park Co., Col.

Rezbanyite. $4PbS.5Bi_2S_3$. Fine-granular, massive. Color lead-gray. G. = 6·1–6·4. From Rezbanya, Hungary.

B. Meta- Division. $RS.As_2S_3$, $RS.Sb_2S_3$, etc.

Zinkenite Group. Orthorhombic

ZINKENITE. Zinckenite.

Orthorhombic. Axes $a : b : c = 0·5575 : 1 : 0·6353$. Crystals seldom distinct; sometimes in nearly hexagonal forms through twinning. Lateral faces longitudinally striated. Also columnar, fibrous, massive.

Cleavage not distinct. Fracture slightly uneven. H. = 3–3·5. G. = 5·30–5·35. Luster metallic. Color and streak steel-gray. Opaque.

Comp. — $PbSb_2S_4$ or $PbS.Sb_2S_3$ = Sulphur 22·3, antimony 41·8, lead 35·9 = 100. Arsenic sometimes replaces part of the antimony.

Pyr., etc. — Decrepitates and fuses very easily; in the closed tube gives a faint sublimate of sulphur, and antimony trisulphide. In the open tube sulphurous fumes and a white sublimate of oxide of antimony; the arsenical variety gives also arsenical fumes. On charcoal is almost entirely volatilized, giving a coating which on the outer edge is white, and near the assay dark yellow; with soda in R.F. yields globules of lead. Soluble in hot hydrochloric acid with evolution of hydrogen sulphide and separation of lead chloride on cooling.

Obs. — Occurs at Wolfsberg in the Harz Mts.; Kinzigtal, Baden; Val Sugana, Tyrol; Oruro, Bolivia; Sevier County, Ark.; San Juan Co., Col.

Andorite. $Ag_2S.2PbS.3Sb_2S_3$. In prismatic, orthorhombic crystals. H. = 3–3·5. G. = 5·5. Color dark gray to black. From Felsőbánya, Hungary; Oruro, Bolivia. *Webnerite* and *Sundtite* are identical with andorite.

Sartorite. PbS. As_2S_3. In slender, striated crystals, probably monoclinic. G. = 5·4. Color dark lead-gray. Occurs in the dolomite of the Binnental.

Platynite. $PbS.Bi_2Se_3$. Rhombohedral. Basal and rhombohedral cleavages. H. = 2–3. G. = 7·98. Color like graphite. Streak shining. In small lamellæ in quartz at Falun, Sweden.

Emplectite. $Cu_2S.Bi_2S_3$. In thin striated prisms. G. = 6·3–6·5. Color grayish white to tin-white. Occurs in quartz at Schwarzenberg and Annaberg, Saxony.

Chalcostibite. Wolfsbergite. $Cu_2S.Sb_2S_3$. In small aggregated prisms; also fine granular, massive. G. = 4·75–5·0. Color between lead-gray and iron-gray. From Wolfsberg in the Harz Mts.; from Huanchaca, Bolivia. *Guejarite* from Spain is the same species.

Galenobismutite. $PbS.Bi_2S_3$; also with Ag,Cu. Crystalline columnar to compact. Color lead-gray to tin-white. G. = 6·9. From Nordmark, Sweden; Poughkeepsie Gulch, Col. (*alaskaite*, argentiferous); material from Falun, Sweden, containing selenium has been named *weibullite* and given the formula, $2PbS.Bi_4S_3Se_3$.

Berthierite. $FeS.Sb_2S_3$. Fibrous massive, granular. G. = 4·0. Color dark steel-gray. From Chazelles and Martouret, Auvergne, France; Charbes, Val de Villé, Alsace; Bräunsdorf, Saxony, etc.

Matildite. $Ag_2S.Bi_2S_3$. In slender, prismatic crystals. G. = 6·9. Color gray. From Morochoca, Peru; Lake City, Col. PLENARGYRITE, from Schapbach, Baden, similar in composition, has been shown to be a mixture.

Miargyrite. $Ag_2S.Sb_2S_3$. In complex monoclinic crystals, also massive. H. = 2–2·5. G. = 5·1–5·30. Luster metallic-adamantine. Color iron-black to steel-gray, in thin splinters deep blood-red. Streak cherry-red. From Bräunsdorf, Saxony; Felsöbánya and Nagybánya, Hungary; Přibram, Bohemia; Zacatecas, Mexico; Bolivia.

Smithite. $Ag_2S.Sb_2S_3$. Monoclinic. Crystals resemble a flattened hexagonal pyramid. One perfect cleavage. H. = 1·5–2. G. = 4·9. Color light red changing to orange-red on exposure to light. Streak vermilion. From the Binnental, Switzerland.

Trechmanite. $Ag_2S.As_2S_3$. Rhombohedral, tetartohedral. Crystals minute with prismatic habit. Good rhombohedral cleavage. H. = 1·5–2. Color and streak scarlet-vermilion. From the Binnental, Switzerland.

Lorandite. A sulpharsenide of thallium, $TlAsS_2$. Monoclinic. Color cochineal-red. From Allchar, Macedonia; Rambler mine, Encampment, Wy.

Vrbaite. $TlAs_2SbS_5$. Orthorhombic. H. = 3·5. G. = 5·3. Color gray-black to dark red in thin splinters. Streak light red. From Allchar, Macedonia.

Hutchinsonite. $(Tl,Ag,Cu)_2S.As_2S_3+PbS.As_2S_3$(?). Orthorhombic. In flattened rhombic prisms. Cleavage *a*(100) good. H. = 1·5–2. G. = 4·6. Color scarlet to red. From the Binnental, Switzerland.

C. Intermediate Division

Baumhauerite. $4PbS.3As_2S_3$. Monoclinic. In complex crystals with varied habit. One perfect cleavage. H. = 3. G. = 3·3. Metallic. Color lead to steel-gray. From the Binnental, Switzerland.

Schirmerite. $3(Ag_2,Pb)S.2Bi_2S_3$. Massive, granular. G. = 6·74. Color lead-gray. Treasury lode, Park Co., Col.

KLAPROTHOLITE. $3Cu_2S.Bi_2S_3$. In furrowed prismatic crystals. G. = 4·6. Color steel-gray. Wittichen, Baden. Probably a mixture and not a definite species.

Rathite. $3PbS.2As_2S_3$. Orthorhombic, in prismatic crystals. Cleavage, *b*(010). H. = 3. G. = 5·41. From the Binnental, Switzerland. *Wiltshireite* is the same species.

Jamesonite Group. $2RS.As_2S_3$, $2RS.Sb_2S_3$, etc. Monoclinic

JAMESONITE.

Monoclinic. Axes: $a : b : c = 0·8316 : 1 : 0·4260$. $\beta = 88° 36'$. mm''' $110 \wedge 1\bar{1}0 = 79° 28'$. In acicular crystals; common in capillary forms; also fibrous massive, parallel or divergent; compact massive.

Cleavage: basal, perfect. Fracture uneven to conchoidal. Brittle. H. = 2–3. G. = 5·5–6·0. Luster metallic. Color steel-gray to dark lead-gray. Streak grayish black. Opaque.

Comp. — $Pb_2Sb_2S_5$ or $2PbS.Sb_2S_3$ = Sulphur 19·7, antimony 29·5, lead

50·8 = 100. Most varieties show a little iron (1 to 3 p. c.), and some contain also silver, copper, and zinc.

It has been suggested that the iron shown by the analyses is an integral part of the mineral and that the formula should be $4PbS.FeS.3Sb_2S_3$ and that the usual jamesonite formula, $2PbS.Sb_2S_3$, belongs to the material commonly called *plumosite*.

Pyr. — Same as for zinkenite, p. 385.

Obs. — Occurs principally in Cornwall; also in Siberia; Hungary; at Valentia d'Alcantara in Spain; at the antimony mines in Sevier Co., Ark.; from Bolivia. Named after Prof. Robert Jameson of Edinburgh (1774–1854).

The *feather ore* occurs at Wolfsberg, etc., in the Harz Mts.; Freiberg, Germany; Schemnitz, Hungary; in Tuscany, near Bottino, Italy. These so-called feather ores may be divided into flexible and brittle, all the latter being referred to jamesonite and the former to either zinkenite, plumosite, boulangerite, or meneghinite.

Warrenite has been shown to probably be a mixture of jamesonite and zinkenite.

Dufrenoysite. $2PbS.As_2S_3$. In highly modified crystals; also massive. Cleavage: *b*(010) perfect. H. = 3. G. = 5·55–5·57. Color blackish lead-gray. From the Binnental, Switzerland, in dolomite.

Cosalite. $2PbS.Bi_2S_3$. Usually massive, fibrous or radiated. G. = 6·39–6·75. Color lead- or steel-gray. Cosala, Province of Sinaloa, Mexico; Bjelke mine (*bjelkite*), Nordmark, Sweden; Deer Park, Wash.; Col.

Kobellite. $2PbS.(Bi,Sb)_2S_3$. Fibrous radiated or granular massive. G. = 6·3. Color lead-gray to steel-gray. From Hvena, Sweden; Ouray, Col.

BRONGNIARDITE. Lead, silver, antimony sulphide. Shown in some cases to be a mixture. A doubtful species.

Plagionite. Heteromorphite. Semseyite. Lead, antimony sulphides ranging from $5PbS_4.Sb_2S_3$ to $9PbS.4Sb_2S_3$. Perhaps a morphotropic series with the vertical crystallographic axis increasing in length with increase in the percentage of lead. Monoclinic. G. = 5·4–5·9. Plagionite from Wolfsberg, Harz Mts.; heteromorphite from Arnsberg, Westphalia; semseyite from Felsőbánya, Hungary and Wolfsberg. *Liveingite* from the Binnental, Switzerland, is said to have the same composition as plagionite. *Bismutoplagionite*, a variety containing bismuth instead of antimony. From Wickes, Jefferson Co., Mon.

SCHAPBACHITE. A lead, silver, bismuth sulphide. From Schapbach, Baden. Shown to be a mixture.

FREIESLEBENITE.

Monoclinic. Axes *a* : *b* : *c* = 0·5871 : 1 : 0·9277; β = 87° 46′. Habit prismatic. G. = 6·2–6·4. Luster metallic. Color and streak light steel-gray inclining to silver-white, also to blackish lead-gray.

Comp. — $(Pb,Ag_2)_5Sb_4S_{11}$ or $5(Pb,Ag_2)S.2Sb_2S_3$.

Obs. – From Freiberg, Saxony; Kapnik and Felsőbánya, Hungary; Hiendelencina, Spain; also from the Augusta Mt., Gunnison Co., Col.

Diaphorite. Like freieslebenite in composition but orthorhombic in form. G. = 5·9. From Přibram, Bohemia; Lake Chelan district, Wash.

BOULANGERITE.

Orthorhombic. Axes *a* : *b* : *c* = 0·5527 : 1 : 0·7478. In prismatic or tabular crystals or crystalline plumose masses; granular, compact. H. = 2·5–3. G. = 6·18. Luster metallic. Color bluish lead-gray; often covered with yellow spots from oxidation. Opaque.

Comp. — $Pb_5Sb_4S_{11}$ or $5PbS.2Sb_2S_3$ = Sulphur 18·9, antimony 25·7, lead 55·4 = 100.

Pyr. — Same as for zinkenite, p. 385.

Obs. — In good crystals from Sala, Sweden; Molières, Depart. du Gard, France; at Nerchinsk, Siberia; Wolfsberg in the Harz Mts. Přibram, Bohemia; near Bottino, Tuscany, Italy. Echo District, Union county, Nev.

Embrithite and *plumbostib* are from Nerchinsk; they correspond nearly to $10PbS.3Sb_2S_3$, but the material analyzed may not have been quite pure.

Mullanite. $5PbS.2Sb_2S_3$. In slender orthorhombic (?) prisms. Cleavage, *c*(001) and *b*(010). Color, steel-gray. Streak, brownish black. H. = 3·5. G = 6·35. Found at Gold Hunter mine, near Mullan, Idaho, and at Iron Mountain mine, near Superior, Mon.

D. Ortho- Division. $3RS.As_2S_3$, $3RS.Sb_2S_3$, etc.

Bournonite Group. Orthorhombic. Prismatic angle 86° to 87°

BOURNONITE. Wheel Ore.

Orthorhombic. Axes: $a : b : c = 0·9380 : 1 : 0·8969$.

mm''', $110 \wedge 1\bar{1}0 = 86° 20'$
co, $001 \wedge 101 = 43° 43'$
cn, $001 \wedge 011 = 41° 53'$
cu, $001 \wedge 112 = 33° 15'$

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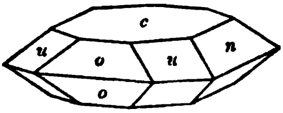

Harz

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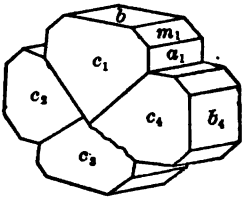

Kapnik

Twins: tw. pl. *m*(110), often repeated, forming cruciform and wheel shaped crystals. Also massive; granular, compact.

Cleavage: *b*(010) imperfect; *a*(100), *c*(001) less distinct. Fracture subconchoidal to uneven. Rather brittle. H. = 2·5–3. G. = 5·7–5·9. Luster metallic, brilliant. Color and streak steel-gray, inclining to blackish lead-gray or iron-black. Opaque.

Comp. — $(Pb,Cu_2)_3Sb_2S_6$ or $3(Pb,Cu_2)S.Sb_2S_3 = PbCuSbS_3$ (if $Pb : Cu_2 = 2 : 1$) = Sulphur 19·8, antimony 24·7, lead 42·5, copper 13·0 = 100.

Pyr., etc. — In the closed tube decrepitates, and gives a dark red sublimate. In the open tube gives sulphur dioxide, and a white sublimate of oxide of antimony. B.B. on charcoal fuses easily, and at first coats the coal white; continued blowing gives a yellow coating of lead oxide; the residue, treated with soda in R.F., gives a globule of copper. Decomposed by nitric acid, affording a blue solution, and leaving a residue of sulphur, and a white powder containing antimony and lead.

Obs. — From Neudorf in the Harz Mts.; also Wolfsberg, Claustal, and Andreasberg; Přibram, Bohemia; Kapnik and Nagybánya, Hungary; Horhausen, Prussia; Liskeard, Cornwall.

In the United States at the Boggs mine, Yavapai Co., Ariz.; also Montgomery Co., Ark.; reported from San Juan Co., Col; Austin, Nev. In Canada, in the township of Marmora, Hastings Co., and Darling, Lanark Co., Ontario.

Seligmannite. $(Pb,Cu_2)_3As_2S_6$ isomorphous with bournonite. Orthorhombic. $a : b : c = 0·9233 : 1 : 0·8734$. In small complex crystals. Commonly twinned with *m*(110) as tw. pl. Color lead-gray. Chocolate streak. H. = 3. Found at Lengenbach quarry, Binnental, Switzerland; reported from Emery, Mon.

Aikinite. $2PbS.Cu_2S.Bi_2S_3$. Acicular crystals; also massive. G. = 6·1–6·8. Color blackish lead-gray. From Berezov near Ekaterinburg, Ural Mts.

Wittichenite. $3Cu_2S.Bi_2S_3$. Rarely in crystals resembling bournonite; also massive. G. = 4·5. Color steel-gray or tin-white. Wittichen, Baden, etc.

Stylotypite. $3(Cu_2,Ag_2,Fe)S.Sb_2S_3$. In orthorhombic crystals, in cruciform twins like bournonite. G. = 4·7–5·2. Color iron-black. Copiapo, Chile; Peru.

Lillianite. $3PbS.BiSbS_3$ and $3PbS.Bi_2S_3$. Orthorhombic. Crystalline and massive. Color steel-gray. Gladhammar, Sweden; Leadville, Col. (argentiferous).

Guitermanite. Perhaps $3PbS.As_2S_3$. Massive, compact. G. = 5·94. Color bluish gray. Zuñi mine, Silverton, Col.

Lengenbachite. $7[Pb,(Ag,Cu)_2]S.2As_2S_3$. Probably triclinic. In thin blade-shaped crystals. One perfect cleavage. Soft. G. = 5·8. Color steel-gray. Streak black. From the Lengenbach quarry, Binnental, Switzerland.

Tapalpite. A sulpho-telluride of bismuth and silver, perhaps $3Ag_2(S,Te).Bi_2(S,Te)_3$. Study of polished specimen shows it to be a mixture of unknown components. Massive, granular. G. = 7·80. Sierra de Tapalpa, Jalisco, Mexico.

Pyrargyrite Group. Rhombohedral-hemimorphic

PYRARGYRITE. Ruby Silver Ore. Dark Red Silver Ore.

Rhombohedral-hemimorphic. Axis: $c = 0·7892$; $0001 \wedge 1011 = 42° 20\frac{1}{2}.'$

ee', $01\bar{1}2 \wedge \bar{1}012 = 42° \ 5'$ vv', $21\bar{3}1 \wedge \bar{2}3\bar{1}1 = 74° 25'$

rr', $10\bar{1}1 \wedge \bar{1}101 = 71° 22'$ vv^{v}, $21\bar{3}1 \wedge 3\bar{1}\bar{2}1 = 35° 12'$

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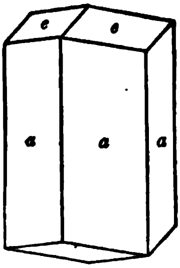

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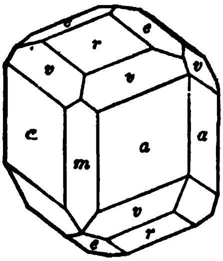

Crystals commonly prismatic. Twins: tw. pl. $a(11\bar{2}0)$, very common, the c axes parallel; $u(10\bar{1}4)$, also common. Also massive, compact.

Cleavage: $r(10\bar{1}1)$ distinct; $e(01\bar{1}2)$ imperfect. Fracture conchoidal to uneven. Brittle. H.=2·5. G.=5·77–5·86; 5·85 if pure. Luster metallic-adamantine. Color black to grayish black, by transmitted light deep red. Streak purplish red. Nearly opaque, but transparent in very thin splinters. Optically − . Refractive indices, $\omega = 3·084$, $\epsilon = 2·881$.

Comp. — Ag_3SbS_3 or $3Ag_2S.Sb_2S_3$ = Sulphur 17·8, antimony 22·3, silver 59·9 = 100. Some varieties contain small amounts of arsenic.

Pyr., etc. — In the closed tube fuses and gives a reddish sublimate of antimony oxysulphide; in the open tube sulphurous fumes and a white sublimate of oxide of antimony. B.B. on charcoal fuses with spirting to a globule, coats the coal white, and the assay is converted into silver sulphide, which, treated in O.F., or with soda in R.F., gives a globule of silver. In case arsenic is present it may be detected by fusing the pulverized mineral with soda on charcoal in R.F. Decomposed by nitric acid with the separation of sulphur and of antimony trioxide.

Obs. — Occurs at Andreasberg in the Harz Mts.; Freiberg, Saxony; Příbram and Joachimstal, Bohemia; Schemnitz and Nagybánya, Hungary; Kongsberg, Norway; Gaudalcanal, Spain; in Cornwall. In Mexico it is worked at Guanajuato and elsewhere as an ore of silver. In Chile with proustite at Chañarcillo near Copiapo.

In Col., not uncommon; thus in Ruby district, Gunnison Co.; with sphalerite in Sneffle's district, Ouray Co., etc. In Nev., at Washoe in Daney Mine; about Austin, Reese river; at Poorman lode, Idaho, in masses with cerargyrite. In N. M., Utah, and Ariz. with silver ores at various points. At Cobalt, Ontario.

Named from πῦρ, *fire*, and ἄργυρος, *silver*, in allusion to the color.

PROUSTITE. Ruby Silver Ore. Light Red Silver Ore.

Rhombohedral-hemimorphic. Axis $c = 0·8039$; $0001 \wedge 10\bar{1}1 = 42° 52'$.

ee', $01\bar{1}2 \wedge \bar{1}012 = 42° 46'$ vv', $21\bar{3}1 \wedge 23\bar{1}1 = 74° 39'$

rr', $10\bar{1}1 \wedge \bar{1}101 = 72° 12'$ vv^{v}, $21\bar{3}1 \wedge 3\bar{1}\bar{2}1 = 35° 18'$

Crystals often acute rhombohedral or scalenohedral. Twins: tw. pl. $u(10\bar{1}4)$ and $r(10\bar{1}1)$. Also massive, compact.

Cleavage: $r(10\bar{1}1)$ distinct. Fracture conchoidal to uneven. Brittle. H. = 2–2·5. G. = 5·57–5·64; 5·57 if pure. Luster admantine. Color scarlet-vermilion; streak same, also inclined to aurora-red. Transparent to translucent. Optically negative. $\omega = 3·084$. $\epsilon = 2·881$.

Comp. — Ag_3AsS_3 or $3Ag_2S.As_2S_3$ = Sulphur 19·4, arsenic 15·2, silver 65·4 = 100.

Pyr., etc. — In the closed tube fuses easily, and gives a faint sublimate of arsenic trisulphide; in the open tube sulphurous fumes and a white crystalline sublimate of arsenic trioxide. B.B. on charcoal fuses and emits odors of sulphur and arsenic; with soda in R.F. gives a globule of silver. Decomposed by nitric acid, with separation of sulphur.

Obs. — Occurs at Freiberg, Johanngeorgenstadt, etc., in Saxony; Joachimstal, Bohemia; in France at Chalanches in Dauphiné and Markirch, Alsace; Guadalcanal in Spain; Sarrabus, Sardinia; in Mexico; Peru; Chile, at Chañarcillo in magnificent crystallizations.

In Col., Ruby distr., Gunnison Co.; Sheridan mine, San Miguel Co.; Yankee Girl mine, Ouray Co.; Montezuma, Summit Co. In Ariz., with silver ores at various points. In Nev., in the Daney mine, and in Comstock lode, rare; Idaho, at the Poorman lode.

Named after the French chemist, J. L. Proust (1755–1826).

Sanguinite. Near proustite in composition. In glittering scales, hexagonal or rhombohedral. From Chañarcillo, Chile.

FALKENHAYNITE. Perhaps $3Cu_2S.Sb_2S_3$. Massive, resembling galena. From Joachimstal, Bohemia. Perhaps identical with stylotypite.

Pyrostilpnite. Like pyrargyrite, $3Ag_2S.Sb_2S_3$. In tufts of slender (monoclinic) crystals. G. = 4·25. Color hyacinth-red. From Andreasberg in the Harz Mts.; Freiberg, Saxony; Přibram, Bohemia; Heazlewood, Tasmania.

Samsonite. $2Ag_2S.MnS.Sb_2S_3$. Monoclinic. Habit prismatic. Color, steel-black, red in transmitted light. Occurs in Samson vein of Andreasberg silver mines, Harz Mts., Germany.

E. Basic Division

Tetrahedrite Group. Isometric-tetrahedral

TETRAHEDRITE. Gray Copper Ore. Fahlerz.

Isometric-tetrahedral. Habit tetrahedral. Twins: tw. pl. *o*(111); also with parallel axes (Fig. 392, p. 163, Fig. 408, p. 166). Also massive; granular, coarse or fine; compact.

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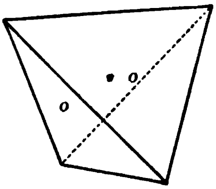

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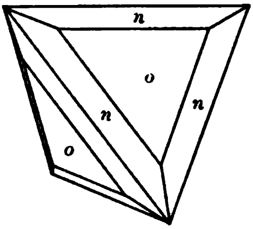

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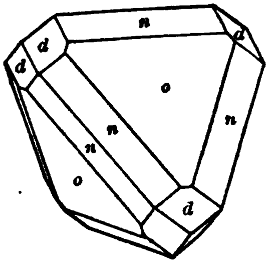

Cleavage none. Fracture subconchoidal to uneven. Rather brittle. H. = 3–4. G. = 4·4–5·1. Luster metallic, often splendent. Color between flint-gray and iron-black. Streak like color, sometimes inclining to brown and cherry-red. Opaque; sometimes subtranslucent (cherry-red) in very thin splinters.

Comp. — Essentially $Cu_8Sb_2S_7$ or $4Cu_2S.Sb_2S_3$ = Sulphur 23·1, antimony 24·8, copper 52·1 = 100.

Antimony and arsenic are usually both present and thus tetrahedrite graduates into the allied species tennantite. There are also varieties containing bismuth, chiefly at the arsenical end of the series, rarely selenium. Further the copper may be replaced by iron, zinc, silver, mercury, lead, manganese, and rarely cobalt and nickel.

Var. — *Ordinary.* Contains little or no silver. Color steel-gray to dark gray and iron-black. G. = 4·75–4·9.

Argentiferous; Freibergite. Contains 3 to 30 p. c. of silver. Color usually steel-gray, lighter than the ordinary varieties; sometimes iron-black; streak often reddish. G. = 4·85–5·0.

Mercurial; Schwatzite. Contains 6 to 17 p. c. of mercury. Color dark gray to iron-black. Luster often dull. G. = 5·10 chiefly.

Malinowskite, from Peru and a similar variety from Arizona, contain 13–16 p. c. of lead.

Pyr., etc. — Differ in the different varieties. In the closed tube all the antimonial kinds fuse and give a dark red sublimate of antimony oxysulphide; if much arsenic is present, a sublimate of arsenic trisulphide first forms. In the open tube fuses, gives sulphurous fumes and a white sublimate of antimony oxide; if arsenic is present, a crystalline volatile sublimate condenses with the antimony; if the ore contains mercury it condenses in minute metallic globules. B.B. on charcoal fuses, gives a coating of the oxides of antimony and sometimes arsenic, zinc, and lead; arsenic is detected by the odor when the coating is treated in R.F. The roasted mineral gives with the fluxes reactions for iron and copper; with soda yields a globule of metallic copper. Decomposed by nitric acid, with separation of sulphur and antimony trioxide.

Diff. — Distinguished by its form, when crystallized, by its deep black color on fracture and brilliant metallic luster. It is harder than bournonite and much softer than magnetite; the blowpipe characters are usually distinctive.

Micro. — In polished sections shows a grayish white color with a smooth surface. Fumes from HNO_3 tarnish mineral slowly to a light brown. With aqua regia slowly effervesces leaving a coating of sulphur and a pitted surface.

Obs. — Often associated with chalcopyrite, pyrite, sphalerite, galena, and various other silver, lead, and copper ores; also siderite. Occurs at many Cornish mines; thus at the Herodsfoot mine, Liskeard, in tetrahedral crystals often coated with iridescent chalcopyrite; the Levant mine near St. Just. In Germany from Andreasberg and Claustal in the Harz Mts.; Freiberg, Saxony; Dillenburg and Horhausen in Nassau; at Müsen, Prussia; various mines in the Black Forest. From Příbram, Bohemia; Kogel near Brixlegg in Tyrol, Austria; Kapnik, Herrengrund, Hungary. In Mexico, at Durango, Guanajuato; Chile; Bolivia, etc. The *argentiferous* variety occurs especially at Freiberg; Příbram; Huallanca in Peru, and elsewhere. The *mercurial* variety at Schmölnitz, Hungary; Schwatz, Tyrol; valleys of Angina and Castello, Tuscany, Italy.

In the United States, tetrahedrite occurs at the Kellogg mines, Ark. In Col., in Clear Creek, Summit and Gilpin Cos.; the Ulay mine, Lake Co.; with pyrargyrite in Ruby district, Gunnison Co., etc. Much of the Colorado "gray copper" is tennantite (see below). In Nev., abundant in Humboldt Co.; near Austin in Lander Co.; Isabella mine, Reese river. In Utah at Bingham Canyon. In Ariz. at the Heintzelman mine; at various points in British Columbia.

Use. — An ore of copper and frequently ore of the other metals, like silver, etc., that it may contain.

TENNANTITE.

Isometric-tetrahedral. Crystals often dodecahedral. Also massive, compact. H. = 3–4. G. = 4·37–4·49. Color blackish lead-gray to iron-black.

Comp. — Essentially $Cu_8As_2S_7$ or $4Cu_2S.As_2S_3$ = Sulphur 25·5, arsenic 17·0, copper 57·5 = 100.

Var. — Often contains antimony and thus graduates into tetrahedrite. The original tennantite from Cornwall contains only copper and iron. In crystals, habit dodecahedral.

Sandbergerite contains 7 p. c. of zinc. *Fredricite* from Sweden has, besides copper, also iron, lead, silver, and tin. *Binnite* from Binnental, Switzerland, is tennantite.

Found at the Cornish mines, particularly at Wheal Jewel in Gwennap, and Wheal Unity in Gwinear; in Germany at Freiberg, Saxony, and at the Wilhelmine mine in the Spessart; at Skutterud, Norway. Near Central City, Idaho Springs and Aspen in Col. At Butte, Mon. At Capelton, Quebec, Canada. Named after the chemist, Smithson Tennant (1761–1815). See further above.

Jordanite. $4PbS.As_2S_3$ Monoclinic; often pseudohexagonal by twinning. G. = 6·39. Color lead-gray. From the Binnental, Switzerland; Nagyág, Transylvania.

Meneghinite. $4PbS.Sb_2S_3$. Orthorhombic. In slender prismatic crystals; also massive. G. = 6·34–6·43. Color blackish lead-gray. From Bottino, Tuscany, Italy; Marble Lake, Barrie Township, Ontario.

GOLDFIELDITE. $5Cu_2S.(Sb,As,Bi)_2(S,Te)_3$. As a crust. Color, dark lead-gray. Conchoidal fracture. H. = 3–3·5. At Mohawk mine, Goldfield, Nev. Probably a mixture.

STEPHANITE. Brittle Silver Ore.

Orthorhombic. Axes $a : b : c = 0{\cdot}6292 : 1 : 0{\cdot}6851$.

mm''', 110 ∧ 1$\bar{1}$0 = 64° 21′ *cd*, 001 ∧ 021 = 53° 52′
cβ, 001 ∧ 101 = 47° 26′ *ch*, 001 ∧ 112 = 32° 45′
ck, 001 ∧ 011 = 34° 25′ *cP*, 001 ∧ 111 = 52° 9′

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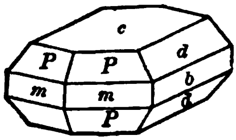

Crystals usually short prismatic or tabular || *c*(001). Twins: tw. pl. *m*(110), often repeated, pseudo-hexagonal. Also massive, compact and disseminated.

Cleavage: *b*(010), *d*(021) imperfect. Fracture subconchoidal to uneven. Brittle. H. = 2–2·5. G. = 6·2–6·3. Luster metallic. Color and streak iron-black. Opaque.

Comp. — Ag_5SbS_4 or $5Ag_2S.Sb_2S_3$ = Sulphur 16·3, antimony 15·2, silver 68·5 = 100. .

Pyr. — In the closed tube decrepitates, fuses, and after long heating gives a faint sublimate of antimony oxysulphide. In the open tube fuses, giving off antimonial and sulphurous fumes. B.B. on charcoal fuses with projection of small particles, coats the coal with oxide of antimony, which after long blowing is colored red from oxidized silver, and a globule of metallic silver is obtained. Soluble in dilute heated nitric acid, sulphur and antimony trioxide being deposited.

Obs. — In veins, with other silver ores, at Freiberg, Schneeberg, etc., in Saxony; Přibram, Bohemia; Schemnitz, Hungary; Andreasberg in the Harz Mts., Germany; Kongsberg, Norway; Sarrabus, Sardinia; Wheal Newton, Cornwall; Arispe, Sonora and elsewhere, Mexico; Peru; Chañarcillo, Chile.

In Nev., in the Comstock lode, Reese river, etc. In Idaho, at the silver mines at Yankee Fork, Queen's River district.

Named after the Archduke Stephen, Mining Director of Austria.

Geocronite. $5PbS.Sb_2S_3$. Rarely in orthorhombic crystals closely resembling those of stephanite; usually massive, granular. G. = 6·4. Color lead-gray. From Sala, Sweden; Val Castello, Tuscany. *Kilbrickenite* from Kilbricken, Co. Clare, Ireland, is the same species.

Beegerite. $6PbS.Bi_2S_3$. Massive, indistinctly crystallized. G. = 7·27. Color light to dark gray. From Park Co., Col.

Ultrabasite. $11Ag_2S.28PbS.2Sb_2S_3.3GeS_2$ Orthorhombic. Color and streak gray-black. H. = 5. G. = 6. From Freiberg, Germany.

Polybasite Group. $9RS_2As_2S_3$, $9RS.Sb_2S_3$. Monoclinic, pseudo-rhombohedral

POLYBASITE.

Monoclinic. Axes $a : b : c = 1{\cdot}7309 : 1 : 1{\cdot}5796$, $\beta = 90° 0'$. Prismatic angle 60° 2′. In short six-sided tabular prisms, with beveled edges; *c*(001) faces with triangular striations; in part repeated twins, tw. pl. *m* (110).

Cleavage: *c*(001) imperfect. Fracture uneven. H. = 2–3. G. = 6·0–6·2. Luster metallic. Color iron-black, in thin splinters cherry-red. Streak black. Nearly opaque.

Comp. — Ag_9SbS_6 or $9Ag_2S.Sb_2S_3$ = Sulphur 15·0, antimony 9·4, silver 75·6 = 100. Part of the silver is replaced by copper; also the antimony by arsenic.

Pry., etc. — In the open tube fuses, gives sulphurous and antimonial fumes, the latter forming a white sublimate, sometimes mixed with crystalline arsenic trioxide. B.B. fuses with spirting to a globule, gives off sulphurous (sometimes arsenical) fumes, and coats the coal with antimony trioxide; with long-continued blowing some varieties give a faint yellowish white coating of zinc oxide, and a metallic globule, which with salt of phosphorus reacts for copper, and cupelled with lead gives pure silver. Decomposed by nitric acid.

Obs. — Occurs in the mines of Guanajuato, from Las Chipas and Arispe, Sonora, Mexico; at Tres Puntos, desert of Atacama, Chile; At Freiberg, Saxony; and Přibram, Bohemia; at Sarrabus, Sardinia. In Nev., at the Reese mines and at the Comstock Lode. In Col., at the Terrible Lode, Clear Creek Co., at Ouray. In Ariz., at the Silver King mine; at Neihart, Mon.

Named from πολύς, *many*, and βάσις, *base*, in allusion to the basic character of the compound.

Pearceite. $9Ag_2S.As_2S_3$. Monoclinic, pseudo-rhombohedral. The arsenical variety of polybasite. From Aspen, Col.; Marysville, Lewis and Clarke Co., Mon.

Polyargyrite. $12Ag_2S.Sb_2S_3$. In indistinct isometric crystals. G. = 6·97. Color iron-black. Wolfach, Baden, Germany.

II. Sulpharsenates, Sulphantimonates; Sulpho-stannates, etc.

Here are included a few minerals, chiefly sulpho-salts of quintivalent arsenic and antimony; also several sulpho-stannates and rare sulpho-germanates.

ENARGITE.

Orthorhombic. Axes: $a : b : c = 0·8711 : 1 : 0·8248$.

Crystals usually small; prismatic faces vertically striated. Twins: tw. pl. $x(320)$ in star-shaped trillings. Also massive, granular, or columnar.

Cleavage : $m(110)$ perfect; $a(100)$, $b(010)$ distinct; $c(001)$ indistinct. Fracture uneven. Brittle. H. = 3. G. = 4·43–4·45. Luster metallic. Color grayish black to iron-black. Streak grayish black. Opaque.

Comp. — Cu_3AsS_4 or $3Cu_2S.As_2S_5$ = Sulphur 32·6, arsenic 19·1, copper 48·3 = 100. Antimony is often present, cf. famatinite.

Pyr. — In the closed tube decrepitates, and gives a sublimate of sulphur; at a higher temperature fuses, and gives a sublimate of sulphide of arsenic. In the open tube, heated gently, the powdered mineral gives off sulphurous and arsenical fumes, the latter condensing to a sublimate containing some antimony oxide. B.B. on charcoal fuses, and gives a faint coating of the oxides of arsenic, antimony, and zinc; the roasted mineral with the fluxes gives a globule of metallic copper. Soluble in aqua regia.

Micro. — In polished sections shows a white color with a smooth surface. With KCN turns black quickly and surface is etched; quickly brown with aqua regia.

Obs. — From Morococha, and Caudalosa, Peru; in Chile and Argentina; Mexico; Matzenköpfl, Brixlegg, Tyrol, Austria; Mancayan, island of Luzon; Kinkwaseki, Formosa.

In the United States, at Brewer's gold mine, Chesterfield dist., S. C.; in Col., at mines near Central City, Gilpin Co.; in Park Co., at the Missouri mine; from Red Mountain district. In southern Utah; also in the Tintic district; Butte, Mon.

Clarite, from the Clara Mine, Schapback, Baden, and *luzonite* from the island of Luzon, Philippines, are identical with enargite.

Use. — Serves as an ore of copper and arsenic.

Famatinite. $3Cu_2S.Sb_2S_5$, isomorphous with enargite. G. = 4·57. Color gray with tinge of copper-red. From the Sierra de Famatina, Argentina; Goldfield, Nev.

Sulvanite. $3Cu_2S.V_2S_5$. Massive. H. = 3·5. G. = 4·0. Color bronze-yellow. Streak nearly black. From near Burra, South Australia.

Xanthoconite. — $3Ag_2S.As_2S_5$. In thin tabular rhombohedral crystals; also massive, reniform. G. = 5. Color orange-yellow. From Freiberg, Germany. *Rittingerite* is the same species.

Epiboulangerite. — $3PbS.Sb_2S_3$. In striated prismatic needles and granular. G. = 6·31. Color dark bluish gray to black. From Altenberg, Saxony, Germany.

Epigenite. — Perhaps $4Cu_2S.3FeS.As_2S_5$. In short prisms resembling arsenopyrite. Color steel-gray. From Wittichen, Baden, Germany.

STANNITE. Tin Pyrites. Bell-metal Ore.

Tetragonal-sphenoidal. Pseudo isometric-tetrahedral through twinning. Twinning, (1) always interpenetrant with *e*(101) as tw. pl., (2) interpenetrant with twin axis ⊥ to *p*(111). Also massive, granular, and disseminated.

Cleavage: cubic, indistinct. Fracture uneven. Brittle. H. = 4. G. = 4·3–4·522; 4·506 Zinnwald. Luster metallic. Streak blackish. Color steel-gray to iron-black, the former when pure; sometimes a bluish tarnish; often yellowish from the presence of chalcopyrite. Opaque.

Comp. — A sulpho-stannate of copper, iron and sometimes zinc, Cu_2FeSnS_4 or $Cu_2S.FeS.SnS_2$ = Sulphur 29·9, tin 27·5, copper 29·5, iron 13·1 = 100.

Pyr., etc.— In the closed tube decrepitates, and gives a faint sublimate; in the open tube sulphurous fumes. B.B. on charcoal fuses to a globule, which in O.F. gives off sulphur dioxide and coats the coal with tin dioxide; the roasted mineral treated with borax gives reactions for iron and copper. Decomposed by nitric acid, affording a blue solution, with separation of sulphur and tin dioxide.

Obs. — In Cornwall formerly found at Wheal Rock; and at Carn Brea; more recently in granite at St. Michael's Mount; also at Stenna Gwynn, etc.; at the Cronebane mine, Co. Wicklow, in Ireland; Zinnwald, in the Erzgebirge, Germany. Crystallized at Oruro, Bolivia. From the Black Hills, S. D.

Argyrodite. A silver sulpho-germanate, Ag_8GeS_6 or $4Ag_2S.GeS_2$. Isometric, crystals usually indistinct; at times they show octahedral and dodecahedral forms with frequent twinning according to the Spinel Law; also massive, compact. H. = 2·5. G. = 6·085–6·266. Luster metallic. Color steel-gray on a fresh fracture, with a tinge of red turning to violet. From the Himmelsfürst mine, Freiberg, Saxony; from Colquechaca and Aullagas, Bolivia.

Canfieldite. Ag_8SnS_6 or $4Ag_2S.SnS_2$, the tin in part replaced by germanium. Isometric, in octahedrons with *d*(110). Twins according to Spinel Law. G. = 6·28. Luster metallic. Color black. Colquechaca, Bolivia.

Teallite. $PbSnS_2$. Orthorhombic? In thin flexible folia. Perfect basal cleavage. H. = 1–2. G. = 6·4. Color blackish gray. Streak black. Probably from Bolivia, exact locality unknown.

Franckeite. $Pb_5Sn_3FeSb_2S_{14}$ or $3PbSnS_2 + Pb_2FeSb_2S_8$. Massive. G. = 5·55. Color blackish gray to black. Las Animas, Bolivia.

Cylindrite. $Pb_3Sn_4FeSb_2S_{14}$ or $3PbSnS_2 + SnFeSb_2S_8$. H. = 2·5–3. G. = 5·42. Luster metallic. Color blackish lead-gray. In cylindrical forms separating under pressure into distinct shells or folia. Poopó, Bolivia.

IV. HALOIDS. — CHLORIDES, BROMIDES, IODIDES; FLUORIDES

I. Anhydrous Chlorides, Bromides, Iodides; Fluorides.
II. Oxychlorides; Oxyfluorides.
III. Hydrous Chlorides; Hydrous Fluorides.

The Fourth Class includes the haloids, that is, the compounds with the halogen elements, chlorine, bromine, iodine, and also the less closely related fluorine.

I. Anhydrous Chlorides, Bromides, Iodides; Fluorides

CALOMEL. Horn Quicksilver.

Tetragonal. Axis c = 1·7234; 001 ∧ 101 = 59° 52′. Crystals sometimes tabular || c(001); also pyramidal; often highly complex.

Cleavage: a(100) rather distinct; also r(111). Fracture conchoidal. Sectile. H. = 1–2. G. = 6·482. Luster adamantine. Color white, yellowish gray, or ash-gray, also grayish, and yellowish white, brown. Streak pale yellowish white. Translucent — subtranslucent. Optically +. ω = 1·970. ϵ = 2·650.

Comp. — Mercurous chloride, HgCl = Chlorine 15·1, mercury 84·9 = 100.

Pyr., etc. — In the closed tube volatilizes without fusion, condensing in the cold part of the tube as a white sublimate; with soda gives a sublimate of metallic mercury. B.B. on charcoal volatilizes, coating the coal white. Insoluble in water, but dissolved by aqua regia; blackens when treated with alkalies.

Obs. — Usually associated with cinnabar. Thus at Moschellandsberg in the Palatinate, Germany; at Idria in Carniola, Austria; Almaden in Spain; at Mt. Avala near Belgrade in Servia. In crystals with many forms from Terlingua, Tex.

Calomel is an old term of uncertain origin and meaning, perhaps from καλός, *beautiful*, and μέλι, *honey*, the taste being sweet, and the compound the *Mercurius dulcis* of early chemistry; or from καλος and μέλας, *black*.

Kleinite. Mercurammonite. A mercury ammonium chloride of uncertain composition. Hexagonal. Crystals short prismatic. Basal cleavage. H. = 3·5. G. = 8·0. Color yellow to orange, darkening on exposure. Volatile. From Terlingua, Tex.

Nantokite. Cuprous chloride, CuCl. Granular, massive. Cleavage cubic. H. = 2–2·5. G. = 3·93. Luster adamantine. Colorless to white or grayish. From Nantoko, Chile; Broken Hill, New South Wales.

Marshite. Cuprous iodide, CuI. Isometric-tetrahedral. Cleavage dodecahedral. H. = 2·5. G. = 5·59. Color oil-brown. n = 2·346. Broken Hill mines, New South Wales.

Halite Group. $\overset{\text{I}}{\text{R}}\text{Cl}$, $\overset{\text{I}}{\text{R}}\text{Br}$, $\overset{\text{I}}{\text{R}}\text{I}$. Isometric

Halite	NaCl	**Embolite**	Ag(Cl,Br)
Sylvite	KCl	**Bromyrite**	AgBr
Sal Ammoniac	$(NH_4)Cl$	**Iodobromite**	Ag(Cl,Br,I)
Cerargyrite	AgCl	**Miersite**	AgI

The Halite Group includes the halogen compounds of the closely related metals, sodium, potassium, and silver, also ammonium (NH_4). They crystallize in the isometric system, the cubic form being the most common. Sylvite and sal-ammoniac are plagiohedral, and the same may be true of the others.

HALITE. Common or Rock Salt.

Isometric. Usually in cubes; crystals sometimes distorted, or with cavernous faces. Also massive, granular to compact; less often columnar.

Cleavage: cubic, perfect. Fracture conchoidal. Rather brittle. H. = 2·5. G. = 2·1–2·6; pure crystals 2·135. Luster vitreous. Colorless or white also yellowish, reddish, bluish, purplish. Transparent to translucent. Soluble; taste saline. n = 1·5442. Highly diathermanous.

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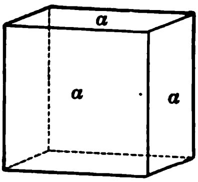

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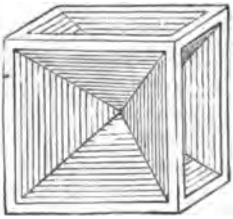

Comp. — Sodium chloride, NaCl = Chlorine 60·6, sodium 39·4 = 100. Commonly mixed with calcium sulphate, calcium chloride, magnesium chloride, and sometimes magnesium sulphate, which render it liable to deliquesce.

Pyr., etc. — In the closed tube fuses, often with decrepitation; when fused on the platinum wire colors the flame deep yellow. After intense ignition the residue gives an alkaline reaction upon moistened test paper. Nitric acid solution gives precipitate of silver chloride upon addition of silver nitrate. Dissolves readily in three parts of water.

Diff. — Distinguished by its solubility (taste), softness, perfect cubic cleavage.

Obs. — Common salt occurs in extensive but irregular beds in rocks of various ages, associated with gypsum, polyhalite, anhydrite, carnallite, clay, sandstone, and calcite; also in solution forming salt springs; similarly in the water of the ocean and salt seas. The deposits of salt have been formed by the gradual evaporation and ultimate drying up of enclosed bodies of salt water. Salt beds formed in this way are subsequently covered by other sedimentary deposits and gradually buried beneath the rock strata thus formed. The salt strata range from a few feet up to more than one hundred feet in thickness and have been found at depths of two thousand feet and more beneath the earth's surface.

The principal salt mines of Europe are at Stassfurt, near Magdeburg, Saxony; Wieliczka, in Galicia; at Hall, in Tyrol, Austria; and along the range through Reichental in Bavaria, Hallein in Salzburg, Hallstadt, Ischl, and Ebensee, in Upper Austria, and Aussee in Styria; in Hungary, at Marmoros and elsewhere; Transylvania; Wallachia, Galicia, and Upper Silesia; in southern and southeastern Russia; Vic and Dieuze in France; Valley of Cardona and elsewhere in Spain; Bex in Switzerland; and Northwich in Cheshire, England.

Salt also occurs, forming hills and covering extended plains, near Lake Urumia, the Caspian Sea, etc. In Algeria; in Abyssinia. In India in enormous deposits in the Salt Range of the Punjab. In China and Asiatic Russia; in South America, in Peru, and at Zipaquera and Nemocon, the former a large mine long explored in the Cordilleras of Colombia; clear salt is obtained from the Cerro de Sal, San Domingo.

In the United States, salt has been found in large amount in central and western N. Y. Salt wells had long been worked in this region, but rock salt is now known to exist over a large area from Ithaca at the head of Cayuga Lake, Tompkins Co., and Canandaigua Lake, Ontario Co., through Livingston Co., also Genesee, Wyoming, and Erie Cos. The salt is found in beds with an average thickness of 75 feet, but sometimes much thicker (in one instance 325 feet), and at varying depths from 1000 to 2000 feet and more; the depth increases southward with the dip of the strata. The rocks belong to the Salina period of the Upper Silurian. Extensive deposits of salt occur in Mich., chiefly in Saginaw, Bay, Midland, Isabella, Detroit, Wayne, Manistee and Mason Counties. Salt has also been found near Cleveland, Ohio, associated with gypsum; in Kan.; in La., extensive beds occur in the southern portion of the state at and in the neighborhood of Petite Anse island. Salt has also been obtained from Nev., Utah, Ariz. and Cal. In Utah and Cal. salt is chiefly obtained by the evaporation of the waters of Great Salt Lake and the ocean.

Brine springs are very numerous in the Middle and Western States. Vast lakes of salt water exist in many parts of the world. The Great Salt Lake in Utah is 2000 square miles in area; L. Gale found in this water 20·196 per cent of sodium chloride. The Dead and Caspian seas are salt, and the waters of the former contain 20 to 26 parts of solid matter in 100 parts. Sodium chloride is the prominent salt present in the ocean.

Use. — The chief uses of salt are for culinary and preservative purposes. Soda ash is also made from it, being employed in the manufacture of glass, soap, bleaching, preparation of other sodium compounds, etc.

Villiaumite. NaF. Isometric. In small carmine colored grains. Soft. G. = 2·8. Refractive index = 1·33. Found in nepheline-syenite from the Islands of Los.

Huantajayite. 20NaCl.AgCl. In cubic crystals and as an incrustation. H. = 2. Not sectile. Color white. From Huantajaya, Tarapacá, Chile.

SYLVITE.

Isometric-plagiohedral. Also in granular crystalline masses; compact.

Cleavage: cubic, perfect. Fracture uneven. Brittle. H. = 2. G. = 1·97–1·99. Luster vitreous. Colorless, white, bluish or yellowish red from inclusions. Soluble; taste resembling that of common salt, but bitter. $n = 1{\cdot}490$.

Comp. — Potassium chloride, KCl = Chlorine 47·6, potassium 52·4 = 100. Sometimes contains sodium chloride.

Pyr., etc. — B.B. in the platinum loop fuses, and gives a violet color to the outer flame. Dissolves completely in water (saline taste). After ignition residue reacts alkaline upon moistened test paper. Solution in nitric acid gives precipitate of silver chloride with silver nitrate.

Obs. — Occurs at Vesuvius, about the fumaroles of the volcano. Also in Germany at Stassfurt, Saxony; and at Leopoldshall (*leopoldite*), Anhalt; at Kalusz in Galicia.

Use. — A source of potash compounds used as fertilizers.

Sal Ammoniac. Ammonium chloride, NH_4Cl. $n = 1{\cdot}642$. Observed as a white incrustation about volcanoes, as at Etna, Vesuvius, etc.

Cerargyrite Group. Isometric-Normal

An isomorphous series of silver haloids in which silver chloride, bromide and iodide may mix in varying proportions. The suggestion has been made that the name cerargyrite be kept as the group name and that the different sub-species be named as follows: *chlorargyrite*, $AgCl$; *bromargyrite*, $AgBr$; *embolite*, $Ag(Cl,Br)$; *iodembolite*, $Ag(Cl,Br,I)$.

CERARGYRITE. Horn Silver.

Isometric. Habit cubic. Twins: tw. pl. $o(111)$. Usually massive and resembling wax; sometimes columnar; often in crusts.

Cleavage none. Fracture somewhat conchoidal. Highly sectile. H. = 1–1·5. G. = 5·552. Luster resinous to adamantine. Color pearl-gray, grayish green, whitish to colorless, rarely violet-blue; on exposure to the light turns violet-brown. Transparent to translucent. $n = 2{\cdot}0611$.

Comp. — Silver chloride, $AgCl$ = Chlorine, 24·7, silver 75·3 = 100. Some varieties contain mercury.

Pyr., etc. — In the closed tube fuses without decomposition. B.B. on charcoal gives a globule of metallic silver. Added to a bead of salt of phosphorus, previously saturated with oxide of copper and heated in O.F., imparts an intense azure-blue to the flame. Insoluble in nitric acid, but soluble in ammonia.

Obs. — Cerargyrite and the related minerals are products of secondary action and are commonly found in the upper parts of silver deposits. Descending waters containing chlorine, bromine or iodine act upon the oxidation products of the primary silver minerals and so precipitate these relatively insoluble compounds. Commonly associated with other silver minerals, with lead, copper and zinc ores and their usual alteration products.

The largest masses are brought from Peru, Chile, Bolivia, and Mexico, where it occurs with native silver. Also once obtained from Johanngeorgenstadt and Freiberg, Saxony; occurs in the Altai Mts.; at Kongsberg in Norway.

In the United States, in Col., near Leadville, Lake Co.; near Breckenridge, Summit Co., and elsewhere. In Nev. near Austin, Lander Co.; at mines of Comstock lode; Tonapah. In Idaho, at the Poorman mine, in crystals; also at various other mines. In Utah, in Beaver, Summit and Salt Lake counties. At Tombstone, Ariz.

Named from *κέρας*, *horn*, and *ἄργυρος*, *silver*.

Use. — An ore of silver.

Embolite. Silver chloro-bromide $Ag(Br,Cl)$, the ratio of chlorine to bromine varying widely. Usually massive. Resembles cerargyrite, but color grayish green to yellowish green and yellow. $n = 2{\cdot}15$. Abundant in Chile. Found also at Broken Hill, New South Wales; Tonapah, Nev.; Leadville, Col.; Yuma County, Ariz.; Georgetown, N. M.

Bromyrite. Silver bromide, $AgBr$. G. = 5·8–6. Color bright yellow to amber-yellow; slightly greenish. $n = 2{\cdot}25$. From Mexico; Chile.

Iodobromite. $2AgCl.2AgBr.AgI$. Isometric. G. = 5·713. Color sulphur-yellow, greenish. $n = 2{\cdot}2$. From near Dernbach, Nassau; Broken Hill, New South Wales.

Miersite. Silver, copper iodide, $4AgI.CuI$. Isometric; tetrahedral. G. = 5·64. In bright yellow crystals from the Broken Hill Silver Mines, New South Wales. *Cuproiodargyrite* from Huantajaya, Peru, belongs here also.

Iodyrite. Silver iodide, AgI. Hexagonal-hemimorphic; usually in thin plates; pale yellow or green. G. = 5·5–5·7. Optically +. ω = 2·182. From Mexico, Chile, etc. Lake Valley, Sierra Co., N. M. In crystals from Broken Hill, New South Wales, and Tonapah, Nev.

Fluorite Group. $\overset{II}{R}F_2,\overset{II}{R}Cl_2$

The species here included are Fluorite, CaF_2, and the rare Hydrophilite, $CaCl_2$. Both are isometric, habit cubic.

FLUORITE or **Fluor Spar.**

Isometric. Habit cubic; less frequently octahedral or dodecahedral; forms *f*(310), *e*(210) (fluoroids) common; also the vicinal form ζ (32·1·0 ?), producing striations on *a*(100) (Fig. 682); hexoctahedron *t*(421) also common with the cube (Fig. 681). Cubic crystals sometimes grouped in parallel position, thus forming a pseudo-octahedron. Twins: tw. pl. *o*(111), commonly penetration-twins (Fig. 682). Also massive; granular, coarse or fine; rarely columnar; compact.

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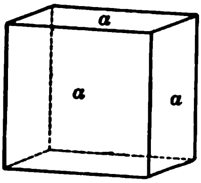

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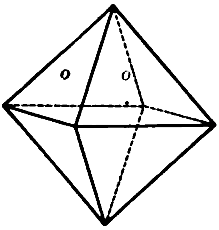

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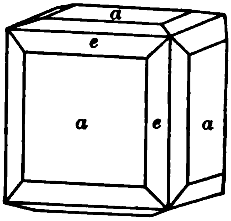

Cleavage: *o*(111) perfect. Fracture flat-conchoidal; of compact kinds splintery. Brittle. H. = 4. G. = 3·01–3·25; 3·18 cryst. Luster vitreous. Color white, yellow, green, rose- and crimson-red, violet-blue, sky-blue, and brown; wine-yellow, greenish blue, violet-blue, most common; red, rare. Streak white. Transparent — subtranslucent. Sometimes shows a bluish fluorescence. Some varieties phosphoresce when heated (p. 251). n = 1·4339.

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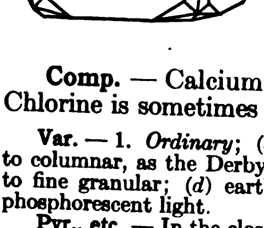

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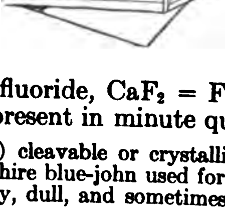

Comp. — Calcium fluoride, CaF_2 = Fluorine 48·9, calcium 51·1 = 100. Chlorine is sometimes present in minute quantities.

Var. — 1. *Ordinary*; (*a*) cleavable or crystallized, very various in colors; (*b*) fibrous to columnar, as the Derbyshire blue-john used for vases and other ornaments; (*c*) coarse to fine granular; (*d*) earthy, dull, and sometimes very soft. *Chlorophane* yields a green phosphorescent light.

Pyr., etc. — In the closed tube decrepitates and sometimes phosphoresces. B. B. in the forceps and on charcoal fuses, coloring the flame orange, to an enamel which reacts alkaline on test paper. Fused in a closed tube with potassium bisulphate gives reaction for fluorine.

Diff. — Distinguished by its crystalline form, octahedral cleavage, relative softness (as compared with certain precious stones, also with the feldspars); etching power when treated with sulphuric acid. Does not effervesce with acid like calcite.

Obs. — Fluorite occurs most commonly as a vein mineral either in deposits in which it is the chief constituent or as a gangue mineral with various metallic ores, especially those of lead and zinc. It is common in sedimentary rocks, being often found in dolomites and limestones. It is also found as a minor accessory mineral in granite and other acid igneous rocks. It occurs as a sublimation product in connection with volcanic rocks.

In the North of England, it is the gangue of the lead veins, which intersect the coal formation in Northumberland, Cumberland, Durham, and Yorkshire. In Derbyshire it is abundant, and also in Cornwall, where the veins intersect metamorphic rocks. The Cumberland and Derbyshire localities especially have afforded magnificent specimens. Common in the mining district of Saxony; from Stolberg, Harz Mts.; fine near Kongsberg in Norway. In the dolomites of St. Gothard occurs in pink octahedrons; from Briens, Switzerland. From Rabenstein, Tyrol, Austria. Rarely in volcanic regions, as in the Vesuvian lava. In colorless transparent crystals from Madoc, Hastings Co., Ontario, Canada.

Some localities in the United States are, Trumbull, Conn. (*chlorophane*); Muscolonge Lake, Jefferson Co., N. Y., and Macomb, St. Lawrence Co., both in very large sea-green cubes; Franklin Furnace, N. J.; Amelia Court House, Va.; Westmoreland, Ver. Fluorite has been mined in the United States chiefly from Western Kentucky and adjacent sections in Hardin and Pope counties, Ill. Also obtained from Jamestown, Boulder County; Evergreen, Jefferson County, and near Rosita, Custer County, Col.; from ten miles north of Deming, N. M.; from Smith, Trousdale and Wilson counties, Tenn.; from Castle Dome district, Ariz.

Use. — As a flux in the making of steel; in the manufacture of opalescent glass; in enameling cooking utensils; the preparation of hydrofluoric acid; sometimes as an ornamental material.

Hydrophilite. Chlorocalcite. Calcium chloride, $CaCl_2$. In white cubic crystals or as an incrustation at Vesuvius. *Bæumlerite* is same material intergrown with halite and tachhydrite from Leinetal, Germany.

The following are from Vesuvius: **Chloromagnesite,** $MgCl_2$; **Scacchite,** $MnCl_2$; **Chloralluminite,** $AlCl_3.6H_2O$; **Molysite,** $FeCl_3$; **Chlormanganokalite,** $4KCl.MnCl_2$.

Sellaite. Magnesium fluoride, MgF_2. In prismatic tetragonal crystals. H. = 5. G. = 2·97–3·15. Colorless. Optically +. ω = 1·378. From the moraine of the Gebroulaz glacier in Savoie, France. *Belonesite* is the same species.

Lawrencite. Ferrous chloride, $FeCl_2$. Occurs in meteoric iron.

Rinneite. $FeCl_2.3KCl.NaCl$. Rhombohedral. In coarse granular masses. Prismatic cleavage. H. = 3. G. = 2·3. Colorless, rose, violet or yellow when fresh, becomes brown on exposure due to oxidation. ω = 1·59. Easily fusible. Astringent taste. Found in Germany at Nordhausen and elsewhere in Saxony and at Diekholzen, Hannover.

Cotunnite. Lead chloride, $PbCl_2$. In acicular crystals (orthorhombic) and in semicrystalline masses. Soft. G. = 5·24. Color white, yellowish. Optically +. β = 2·217. From Vesuvius; also Tarapacá, Chile.

Tysonite. Fluoride of the cerium metals, $(Ce,La,Di)F_3$. In thick hexagonal prisms, and massive. Cleavage: *c*(001), perfect. H. = 4·5–5. G. = 6·13. Color pale wax-yellow, changing to yellowish and reddish brown. From the granite of Pike's Peak, El Paso Co., Col. *Fluocerite*, from Österby, Sweden, is propably the same species.

Yttrofluorite. $(Ca_3,Y_2)F_6$, near *yttrocerite*. Isometric. In granular masses. Imperfect octahedral cleavage. H. = 4·5. G. = 3·55. Color yellow, also with brown or green shades. n = 1·46. Found in pegmatite in northern Norway.

CRYOLITE.

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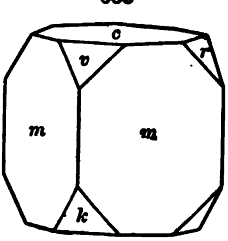

Monoclinic. Axes $a : b : c$ = 0·9663 : 1 : 1·3882; β = 89° 49′.

mm‴, 110 ∧ $1\bar{1}0$ = 88° 2′. *ck*, 001 ∧ $\bar{1}01$ = 55° 17′.
cm, 001 ∧ 110 = 89° 52′. *cr*, 001 ∧ 011 = 54° 14′.
cv, 001 ∧ 101 = 55° 2′. *cp*, 001 ∧ 111 = 63° 18′.

Crystals often cubic in aspect and grouped in parallel position; often with twin lamellæ. Massive.

Parting at times due to twinning lamellæ parallel to *c*(001), *m*(110) and *k*($\bar{1}01$). Fracture uneven. Brittle. H. = 2·5. G. = 2·95–3·0. Luster vitreous to greasy; somewhat pearly on *c*(001). Colorless to snow-white, sometimes reddish or brownish to brick-red or even black. Transparent to translucent. Optically +. Mean index, 1·364.

Comp. — A fluoride of sodium and aluminium, Na_3AlF_6 or $3NaF.AlF_3$ = Fluorine 54·4, aluminium 12·8, sodium 32·8 = 100. A little iron sesquioxide is sometimes present as impurity.

Pyr., etc. — Fusible in small fragments in the flame of a candle. Heated in C. T. with potassium bisulphate gives fluorine reaction. In the forceps fuses very easily, coloring the flame yellow. On charcoal fuses easily to a clear bead, which on cooling becomes opaque; after long blowing, the assay spreads out, the fluoride of sodium is absorbed by the coal, a suffocating odor of fluorine is given off, and a crust of alumina remains, which, when heated with cobalt solution in O.F., gives a blue color. Soluble in sulphuric acid, with evolution of hydrofluoric acid.

Diff. — Distinguished by its extreme fusibility. Because of its low index of refraction the powdered mineral becomes almost invisible when placed in water. Its planes of parting (resembling cubic cleavage) and softness are characteristic.

Obs. — Occurs in a bay in Arksukfiord, in West Greenland, at Ivigtut (or Evigtok), about 12 m. from the Danish settlement of Arksuk, where it constitutes a large bed in a granitic vein in a gray gneiss. Cryolite and its alteration products, pachnolite, thomsenolite, prosopite, etc., also occur in limited quantity at the southern base of Pike's Peak, El Paso county, Col., north and west of Saint Peter's Dome.

Named from *κρύος*, *frost*, *λίϑος*, *stone*, hence meaning *ice-stone*, in allusion to the translucency of the white masses.

Use. — In the manufacture of sodium salts, certain kinds of glass and porcelain, and as a flux in the electrolytic process for the production of aluminum.

Cryolithionite is a variety of cryolite with half the sodium replaced by lithium. G. = 2·78. Refractive index 1·34. Associated with cryolite at Ivigtut.

Chiolite. $5NaF.3AlF_3$. In small pyramidal crystals (tetragonal); also massive granular. Cleavages, *c*(001) perfect, *p*(111) distinct. H. = 3·5–4. G. = 2·84–2·90. Color snow-white. Optically −. ω = 1·349. From near Miask in the Ilmen Mts., Russia; also with the Greenland cryolite.

Hieratite. A fluoride of potassium and silicon. In grayish stalactitic concretions; isometric. From the fumaroles of the crater of Vulcano, Lipari Islands.

II. Oxychlorides, Oxyfluorides

ATACAMITE.

Orthorhombic. Axes $a : b : c$ = 0·6613 : 1 : 0·7515.

mm'', 110 ∧ $\bar{1}$10 = 66° 57'.
ee', 011 ∧ 0$\bar{1}$1 = 73° 51'.
rr''', 111 ∧ 1$\bar{1}$1 = 52° 48'.
mr, 110 ∧ 111 = 36° 16½'.

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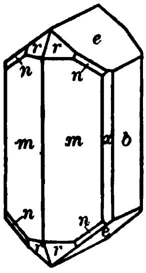


Commonly in slender prismatic crystals, vertically striated. Twins according to a complex law. (*Paratacamite* is twinned atacamite.) In confused crystalline aggregates; also massive, fibrous or granular to compact; as sand.

Cleavage: *b*(010) highly perfect. Fracture conchoidal. Brittle. H. = 3–3·5. G. = 3·75–3·77. Luster adamantine to vitreous. Color bright green of various shades, dark emerald-green to blackish green. Streak apple-green. Transparent to translucent. Optically −. α = 1·831. β = 1·861. γ = 1·880.

Comp. — $Cu_2ClH_3O_3$ or $CuCl_2.3Cu(OH)_2$ = Chlorine 16·6, copper 14·9, cupric oxide 55·8, water 12·7 = 100.

Pyr., etc. — In the closed tube gives off much water, and forms a gray sublimate. B.B. on charcoal fuses, coloring the O.F. azure-blue, with a green edge, and giving two coatings, one brownish and the other grayish white; continued blowing yields a globule of metallic copper; the coatings, touched with the R.F., volatilize, coloring the flame azure-blue. In acids easily soluble.

Obs. — Originally from Atacama in the northern part of Chile; also found at Collahurasi, Tarapacá and elsewhere in Chile and Bolivia; at Wallaroo and Bimbowrie, in South Australia; at Gloncurry, Queensland; at St. Just in Cornwall. In the United States, with cuprite, etc., at the United Verde mine, Jerome, Ariz.

Percylite. A lead-copper oxychloride, perhaps $PbCl_2.CuO.H_2O$. In sky-blue cubes. From Sonora, Mexico; Atacama, Chile; Bolivia, etc.

Boleite. $9PbCl_2.8CuO.3AgCl.9H_2O$. Tetragonal, pseudo-isometric. Twinned to form pseudo cubes. **Pseudo-boleite.** $5PbCl_2.4CuO.6H_2O$. Tetragonal. **Cumengite.** $4PbCl_2.4CuO.5H_2O$. Tetragonal. Pseudo-boleite and cumengite occur in parallel growth upon crystals of boleite. Boleite and pseudo-boleite have pearly luster on cleavage, while cumengite has not. All three deep blue in color, the first two showing a greenish tinge in powder. Found at Boleo, near Santa Rosalia, Lower California.

Matlockite. Lead oxychloride, Pb_2OCl_2. In tabular tetragonal crystals. G. = 7·21. Luster adamantine to pearly. Color yellowish or slightly greenish. Optically —. ω =2·15. From Cromford, near Matlock, Derbyshire.

Mendipite. $Pb_3O_2Cl_2$ or $PbCl_2.2PbO$. In fibrous or columnar masses; often radiated. H. = 2·5–3. G. = 7–7·1. Color white. Index, 1·93. From the Mendip Hills, Somersetshire, England; near Brilon, Westphalia.

Lorettoite. $6PbO.PbCl_2$. Tetragonal? Coarse fibers or blades. Perfect basal cleavage. G. = 7·6. H. = 3. Fusible at 1. Color honey-yellow. Uniaxial, —. Indices, 2·37–2·40. From Loretto, Tenn.

Laurionite. $PbClOH$ or $PbCl_2.Pb(OH)_2$. In minute prismatic colorless crystals (orthorhombic), in ancient lead slags at Laurion, Greece. Optically — . β = 2·116. **Paralaurionite.** Same composition as laurionite but monoclinic. From Laurion. *Rafaelite* from Chile is the same mineral. Suggested that laurionite is the same as paralaurionite but owing to submicroscopic twinning has apparently orthorhombic symmetry. **Fiedlerite,** associated with laurionite, is probably also a lead oxychloride; in colorless monoclinic crystals.

Penfieldite. Pb_3OCl_2 or $PbO.2PbCl_2$. In white hexagonal crystals. Laurion, Greece.

Daviesite. A lead oxychloride of uncertain composition. In minute colorless prismatic crystals (orthorhombic) from the Mina Beatriz, Sierra Gorda, Atacama, Chile.

Schwartzembergite. Probably $Pb(I,Cl)_2.2PbO$. In druses of small crystals; also in crusts. G. = 6·2. Color honey-yellow. Desert of Atacama, Chile.

Nocerite. Perhaps $2(Ca,Mg)F_2(Ca,Mg)O(?)$. In white hexagonal acicular crystals from bombs in the tufa of Nocera, Italy.

Koenenite. An oxychloride of aluminium and magnesium. Rhombohedral. Perfect cleavage yielding flexible folia. Very soft. G. = 2·0. Color red, due to included hematite. From near Volpriehausen in the Solling, Germany.

Daubreeite. An earthy yellowish oxychloride of bismuth. From Bolivia.

The following are oxychlorides of mercury from the mercury deposits at Terlingua, Texas. Associated minerals are montroydite, calomel, native mercury and calcite.

Eglestonite. Hg_4Cl_2O. Isometric in minute crystals of dodecahedral habit. Many forms observed. H. = 2–3. G. = 8·3. Luster adamantine to resinous. Color brownish yellow darkening on exposure to black. n = 2·49. Volatile.

Terlinguaite. Hg_2ClO. Monoclinic. In small striated prismatic crystals elongated parallel to the b-axis. Many forms observed. Cleavage perfect. H. = 2–3. G = 8·7. Luster adamantine. Color sulphur-yellow changing to olive-green on exposure.

III. Hydrous Chlorides, Hydrous Fluorides, etc.

CARNALLITE.

Orthorhombic. Crystals rare. Commonly massive, granular.

No distinct cleavage. Fracture conchoidal. Brittle. H. = 1. G = 1·60. Luster shining, greasy. Color milk-white, often reddish. Transparent to translucent. Strongly phosphorescent. Optically +. 2 V = 70°. α =1·466. β = 1·475. γ = 1·494. Taste bitter. Deliquescent.

Comp. — $KMgCl_3.6H_2O$ or $KCl.MgCl_2.6H_2O$ = Chlorine 38·3, potassium 14·1, magnesium 8·7, water 39·0 = 100.

Obs. — Occurs at Stassfurt, in beds, alternating with thinner beds of common salt and kieserite. In large crystals from Beienrode, near Königshütte, Silesia.

Use. — Carnallite is a source of potash compounds used in fertilizers.

DOUGLASITE, associated with carnallite, is said to be $2KCl.FeCl_2.2H_2O$.

Bischofite. $MgCl_2.6H_2O$. Crystalline-granular; colorless to white. Optically +. $\beta = 1·507$. From Leopoldshall and Stassfurt, Prussia.

Kremersite. $KCl.NH_4Cl.FeCl_3.H_2O$. In red octahedrons. From Vesuvius and Mt. Etna, Sicily.

Mosesite. A mercury-ammonium compound containing chlorine, sulphur trioxide and water. Near *kleinite* in composition. Isometric. Minute octahedrons. Spinel twins. H. = 3+. Color yellow. Doubly refracting at ordinary temperatures. Found sparingly at Terlingua, Texas.

Erythrosiderite. $2KCl.FeCl_3.H_2O$. In red tabular crystals. Vesuvius.

Tachhydrite. $CaCl_2.2MgCl_2.12H_2O$. In wax- to honey-yellow masses. From Stassfurt, Germany.

Fluellite. $AlF_3.H_2O$. In colorless or white rhombic pyramids. Index, 1·47. From Stenna Gwyn, Cornwall.

Prosopite. $CaF_2.2Al(F,OH)_3$. In monoclinic crystals, or granular massive. H. = 4·5. G. = 2·88. Colorless, white, grayish. $\beta = 1·502$. From Altenberg, Saxony; St. Peter's Dome near Pike's Peak, Col.; Utah.

Pachnolite and **Thomsenolite**, occurring with cryolite in Greenland, Col., and Ural Mts., have the same composition, $NaF.CaF_2.AlF_3.H_2O$. Both occur in monoclinic prismatic crystals; prismatic angle for pachnolite, 98° 36′, crystal twins, orthorhombic in aspect. $\beta = 1·413$. For thomsenolite, 89° 46′, crystals often resembling cubes, also prismatic; distinguished by its basal cleavage; also massive. $\beta = 1·414$.

Gearksutite. $CaF_2.Al(F,OH)_3.H_2O$. Earthy, clay-like. Index, 1·448. Occurs with cryolite.

Ralstonite. $(Na_2,Mg)F_2.3Al(F,OH)_3.2H_2O$. In colorless to white, isometric, octahedrons. H. = 4·5. G. = 2·56–2·62. $n = 1·43$. With the Greenland cryolite.

Creedite. $2CaF_2.2Al(F,OH)_3.CaSO_4.2H_2O$. Monoclinic. In grains, prismatic crystals and radiating masses. Usually colorless, rarely purple. H. = 3·5. G. = 2·71. Perfect cleavage. Indices, 1·46–1·49. $2V = 64°$. $Y = b$ axis. Fusible with intumescence. Soluble in acids. Found near Wagon Wheel Gap, Creed Quadrangle, Col.

Tallingite. A hydrated copper chloride from the Botallack mine, Cornwall; in blue globular crusts.

Yttrocerite. $(Y,Er,Ce)F_3.5CaF_2.H_2O$. Massive-cleavable to granular and earthy. H. = 4–5. G. = 3·4. Color violet-blue, gray, reddish brown. From near Falun, Sweden, etc.

V. OXIDES

I. Oxides of Silicon.

II. Oxides of the Semi-Metals: Tellurium, Arsenic, Antimony, Bismuth; also Molybdenum, Tungsten.

III. Oxides of the Metals.

The Fifth Class, that of the OXIDES, is subdivided into three sections, according to the positive element present. The oxides of the non-metal silicon are placed by themselves, but it will be noted that the compounds of the related element titanium are included with those of the metals proper. This last is made necessary by the fact that in one of its forms TiO_2 is isomorphous with MnO_2 and PbO_2.

A series of oxygen compounds which are properly to be viewed as salts, *e.g.*, the species of the Spinel Group and a few others, are for convenience also included in this class.

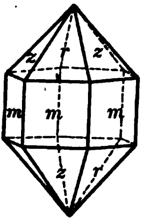
I. Oxides of Silicon

QUARTZ.

Rhombohedral-trapezohedral. Axis: $c = 1{\cdot}09997$.

rr', $10\bar{1}1 \wedge \bar{1}101 = 85° 46'$. mz, $10\bar{1}0 \wedge 01\bar{1}1 = 66° 52'$.
rz, $10\bar{1}1 \wedge 01\bar{1}1 = 46° 16'$. ms, $10\bar{1}0 \wedge 11\bar{2}1 = 37° 58'$.
mr, $10\bar{1}0 \wedge 10\bar{1}1 = 38° 13'$. mx, $10\bar{1}0 \wedge 51\bar{6}1 = 12° 1'$.

685



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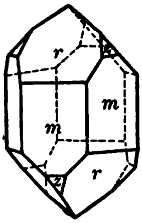

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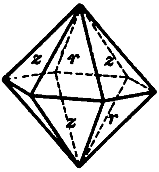

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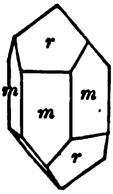

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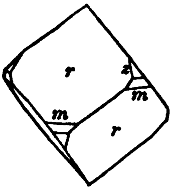

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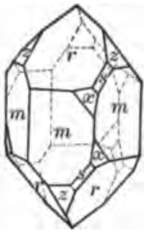

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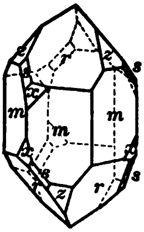


Crystals commonly prismatic, with the $m(10\bar{1}0)$ faces horizontally striated; terminated commonly by the two rhombohedrons, $r(10\bar{1}1)$ and $z(01\bar{1}1)$, in nearly equal development, giving the appearance of a hexagonal pyramid; when one rhombohedron predominates it is in almost all cases *r*. Often in double six-sided pyramids or *quartzoids* through the equal development of *r* and *z*; when *r* is relatively large the form then has a cubic aspect (rr' = 85° 46′). Crystals frequently distorted, when the correct orientation may be obscure except as shown by the striations on *m*. Crystals often elongated to acicular forms, and tapering through the oscillatory combination of successive rhombohedrons with the prism. Occasionally twisted or bent. Frequently in radiated masses with a surface of pyramids, or in druses.

Simple crystals are either right- or left-handed. On a *right-handed* crystal (Fig. 690) the right trigonal pyramid, $s(11\bar{2}1)$, if present, lies to the right of the *m* face, which is below the predominating positive rhombohedron *r*, and with this belong the positive right trapezohedrons, as $x(51\bar{6}1)$. On a *left-handed* crystal (Fig. 691), *s* lies to the left of the *m* below *r*. The right- and left-handed forms occur together only in twins. In the absence of trapezohedral faces the striations on *s* (∥ edge r/m), if distinct, serve to distinguish the faces *r* and *z*, and hence show the right- and left-handed character of the crystals. The right- and left-handed character is also revealed by etching (Art. **286**) and by pyro-electricity (Art. **438**).

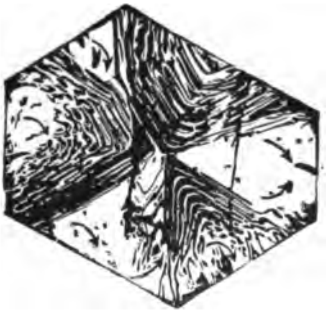
Thermal study of quartz shows that it exists in two modifications, known as α- and β-quartz. α-quartz is apparently hexagonal, trapezohedral-tetartohedral and is formed at temperatures below 575° while β-quartz is hexagonal, trapezohedral-hemihedral and forms at temperatures ranging from 575° to 800°. Above 800° tridymite is formed. The crystal angles of α-quartz change with increase of temperature up to 575°, the inversion point to β-quartz, while beyond this point they remain nearly constant. In a similar manner at this point there is a sudden marked lowering of the refractive indices and birefringence. α-quartz occurs in veins and geodes and large pegmatites while the β modification is found in graphite granite, granite pegmatites, and porphyries. Tridymite when heated to about 1470° passes over into cristobalite. Quartz, tridymite and cristobalite are probably to be considered as polymers of the fundamental molecule, SiO_2.

Twins: (1) tw. axis *c*, all axes parallel. (2) Tw. pl. *a*, sometimes called the *Brazil law*, usually as irregular penetration-twins (Fig. 692). (3) Tw. pl. ξ (11$\bar{2}$2), contact-twins, the axes crossing at angles of 84° 33′ and with a prism face in common to the two individuals. (4) Tw. pl. *r*(10$\bar{1}$1). See further p. 168 and Figs. 427–429. Massive forms common and in great variety, passing from the coarse or fine granular and crystalline kinds to those which are flint-like or cryptocrystalline. Sometimes mammillary, stalactitic, and in concretionary forms; as sand.

Cleavage not distinctly observed; sometimes fracture surfaces (|| *r*(10$\bar{1}$1), *z*(01$\bar{1}$1) and *m*(10$\bar{1}$0), developed by sudden cooling after being heated (see Art. **279**). Fracture conchoidal to subconchoidal in crystallized forms, uneven to splintery in some massive kinds. Brittle to tough. H. = 7. G. = 2·653–2·660 in crystals; cryptocrystalline forms somewhat lower (to 2·60) if pure, but impure massive forms (*e.g.*, jasper) higher. Luster vitreous, sometimes greasy; splendent to nearly dull. Colorless when pure; often various shades of yellow, red, brown, green, blue, black. Streak white, of pure varieties; if impure, often the same as the color, but much paler. Transparent to opaque.

Optically +. Double refraction weak. Polarization circular; right-handed or left-handed, the optical character corresponding to right- and left-handed character of crystals, as defined above; in twins (law 2), both right and left forms sometimes united, sections then often showing Airy's spirals in the polariscope (cf. Art. **394**, p. 270, and Fig. 692). Rotatory power proportional to thickness of plate. Refractive indices for the D line, $\omega = 1{\cdot}54418$, $\epsilon = 1{\cdot}55328$; also rotatory power for section of 1^{mm} thickness, $\alpha = 21{\cdot}71$ (D line). Pyroelectric; also electric by pressure or piezo-electric. See Arts. **438**, **439**. On etching-figures, see Arts. **286**, **287**.

692



Basal section in polarized light, showing interpenetration of right- and left-handed portions. Des Cloizeaux.

Comp. — Silica, or silicon dioxide, SiO_2 = Oxygen 53·3, silicon 46·7 = 100.

In massive varieties often mixed with a little opal silica. Impure varieties contain iron oxide, calcium carbonate, clay, sand, and various minerals as inclusions.

Artif. — Quartz has been produced artificially in numerous ways. Recently crystals have been obtained at temperatures below 760° from melts containing dissolved silica which were composed of (1) a mixture of potassium and lithium chlorides, (2) vanadic acid, (3) sodium tungstate. At higher temperatures tridymite crystals formed.

Var. — A. PHENOCRYSTALLINE: Crystallized, vitreous in luster. B. CRYPTOCRYSTALLINE: Flint-like, massive.

The first division includes all ordinary vitreous quartz, whether having crystalline faces or not. The varieties under the second are in general acted upon somewhat more by attrition, and by chemical agents, as hydrofluoric acid, than those of the first. In all kinds made up of layers, as agate, successive layers are unequally eroded.

A. PHENOCRYSTALLINE OR VITREOUS VARIETIES

Ordinary Crystallized; Rock Crystal. — Colorless quartz, or nearly so, whether in distinct crystals or not. Here belong the Bristol diamonds, Lake George diamonds, Brazilian pebbles, etc. Some variations from the common type are: (*a*) cavernous crystals; (*b*) cap-quartz made up of separable layers or caps; (*c*) drusy quartz, a crust of small or minute quartz crystals; (*d*) radiated quartz, often separable into radiated parts, having pyramidal terminations; (*e*) fibrous, rarely delicately so, as a kind from Griqualand West, South Africa, altered from crocidolite (see *cat's-eye* below, also crocidolite, p. 493).

Asteriated; Star-quartz. — Containing within the crystal whitish or colored radiations along the diametral planes. Occasionally exhibits distinct asterism.

Amethystine; Amethyst. — Clear purple, or bluish violet. Color perhaps due to manganese.

Rose. — Rose-red or pink, but becoming paler on exposure. Commonly massive. Luster sometimes a little greasy. Color perhaps due to titanium.

Yellow; False Topaz or *Citrine.* — Yellow and pellucid; resembling yellow topaz.

Smoky; Cairngorm Stone. — Smoky yellow to dark smoky brown, and often transparent; varying to brownish black. Color is probably due to some organic compound (Forster). Called *cairngorms* from the locality at Cairngorm, southwest of Banff, in Scotland. The name *morion* is given to nearly black varieties.

Milky. — Milk-white and nearly opaque. Luster often greasy.

Siderite, or *Sapphire-quartz.* — Of indigo or Berlin-blue color; a rare variety.

Sagenitic. — Inclosing acicular crystals of rutile. Other included minerals in acicular forms are: black tourmaline; göthite; stibnite; asbestus; actinolite; hornblende; epidote.

Cat's-eye exhibits opalescence, but without prismatic colors, especially when cut *en cabochon*, an effect sometimes due to fibers of asbestus. Also present in the siliceous pseudomorphs, after crocidolite, called *tiger-eye* (see crocidolite). The highly-prized Oriental cat's-eye is a variety of chrysoberyl.

Aventurine. — Spangled with scales of mica, hematite, or other mineral.

Impure from the presence of distinct minerals distributed densely through the mass. The more common kinds are those in which the impurities are: (*a*) *ferruginous*, either red or yellow, from anhydrous or hydrous iron sesquioxide; (*b*) *chloritic*, from some kind of chlorite; (*c*) *actinolitic;* (*d*) *micaceous;* (*e*) *arenaceous*, or sand.

Containing liquids in cavities. The liquid, usually water (pure, or a mineral solution), or some petroleum-like compound. Quartz, especially smoky quartz, also often contains inclusions of both liquid and gaseous carbon dioxide.

B. CRYPTOCRYSTALLINE VARIETIES

Chalcedony. — Having the luster nearly of wax, and either transparent or translucent. G. = 2·6–2·64. Color white, grayish, blue, pale brown to dark brown, black. Also of other shades, and then having other names. Often mammillary, botryoidal, stalactitic, and occurring lining or filling cavities in rocks. It often contains some disseminated opal-silica. The thermal study of *chalcedony* shows that it differs from quartz and may be therefore a distinct species. The name *enhydros* is given to nodules of chalcedony containing water, sometimes in large amount. Embraced under the general name chalcedony is the crystalline form of silica which forms concretionary masses with radial-fibrous and concentric structure, and which, as shown by Rosenbusch, is optically *negative*, unlike true quartz. It has $n = 1·537$; G. = 2·59–2·64. Often in spherulites, showing the spherulitic interference-figure. *Lussatite* of Mallard has a like structure, but is optically + and has the specific gravity and refractive index of opal. It may be a fibrous form of *tridymite.* See also quartzine, p. 407.

Carnelian. Sard. — A clear red chalcedony, pale to deep in shade; also brownish red to brown.

Chrysoprase. — An apple-green chalcedony, the color due to nickel oxide.

Prase. — Translucent and dull leek-green.

Plasma. — Rather bright green to leek-green, and also sometimes nearly emerald-green, and subtranslucent or feebly translucent. *Heliotrope*, or *Blood-stone*, is the same stone essentially, with small spots of red jasper, looking like drops of blood.

Agate. — A variegated chalcedony. The colors are either (*a*) banded; or (*b*) irregularly clouded; or (*c*) due to visible impurities as in moss agate, which has brown moss-like or dendritic forms, as of manganese oxide, distributed through the mass. The bands are delicate parallel lines, of white, pale and dark brown, bluish and other shades; they are sometimes straight, more often waving or zigzag, and occasionally concentric circular.

The bands are the edges of layers of deposition, the agate having been formed by a deposit of silica from solutions intermittently supplied, in irregular cavities in rocks, and deriving their concentric waving courses from the irregularities of the walls of the cavity. The layers differ in porosity, and therefore agates may be varied in color by artificial means, and this is done now to a large extent with the agates cut for ornament. There is also *agatized wood;* wood petrified with clouded agate.

Onyx. — Like agate in consisting of layers of different colors, white and black, white and red, etc., but the layers in even planes, and the banding straight, and hence its use for cameos.

Sardonyx. — Like onyx in structure, but includes layers of carnelian (sard) along with others of white or whitish, and brown, and sometimes black colors.

Agate-jasper. — An agate consisting of jasper with veinings of chalcedony.

Siliceous sinter. — Irregularly cellular quartz, formed by deposition from waters containing silica or soluble silicates in solution. See also under opal, p. 408.

Flint. — Somewhat allied to chalcedony, but more opaque, and of dull colors, usually gray, smoky brown, and brownish black. The exterior is often whitish, from mixture with lime or chalk, in which it is embedded. Luster barely glistening, subvitreous. Breaks with a deeply conchoidal fracture, and a sharp cutting edge. The flint of the chalk formation consists largely of the remains of diatoms, sponges, and other marine productions. The coloring matter of the common kind is mostly carbonaceous matter. Flint implements play an important part among the relics of early man.

Hornstone. — Resembles flint, but is more brittle, the fracture more splintery. *Chert* is a term often applied to hornstone, and to any impure flinty rock, including the jaspers.

Basanite; Lydian Stone, or *Touchstone.* — A velvet-black siliceous stone or flinty jasper, used on account of its hardness and black color for trying the purity of the precious metals. The color left on the stone after rubbing the metal across it indicates to the experienced eye the amount of alloy. It is not splintery like hornstone.

Jasper. — Impure opaque-colored quartz; commonly red, also yellow, dark green and grayish blue. *Striped* or *riband jasper* has the colors in broad stripes. *Porcelain jasper* is nothing but baked clay, and differs from true jasper in being B.B. fusible on the edges.

C. Besides the above there are also:

Granular Quartz, Quartz-rock, or *Quartzite.* — A rock consisting of quartz grains very firmly compacted; the grains often hardly distinct. *Quartzose Sandstone, Quartz-conglomerate.* — A rock made of pebbles of quartz with sand. The pebbles sometimes are jasper and chalcedony, and make a beautiful stone when polished. *Itacolumite,* or *Flexible Sandstone.* — A friable sand-rock, consisting mainly of quartz-sand, but containing a little mica, and possessing a degree of flexibility when in thin laminæ. *Buhrstone,* or Burrstone. — A cellular, flinty rock, having the nature in part of coarse chalcedony.

Pseudomorphous Quartz. — Quartz appears also under the forms of many of the mineral species, which it has taken through either the alteration or replacement of crystals of those species. The most common quartz pseudomorphs are those of calcite, barite, fluorite, and siderite. *Silicified wood* is quartz pseudomorph after wood (p. 326).

Pyr., etc. — B.B. unaltered; with borax dissolves slowly to a clear glass; with soda dissolves with effervescence; unacted upon by salt of phosphorus. Insoluble in hydrochloric acid, and only slightly acted upon by solutions of fixed caustic alkalies, the cryptocrystalline varieties to the greater extent. Soluble only in hydrofluoric acid. When fused and cooled it becomes opal-silica having $G. = 2{\cdot}2$.

Diff. — Characterized in crystals by the form, glassy luster, and absence of cleavage; also in general by hardness and infusibility.

Micro. — Easily recognized in rock sections by its low refraction ("low relief," p. 212) and low birefringence ($\epsilon - \omega = 0{\cdot}009$); the interference colors in good sections not rising above yellow of the first order; also by its limpidity and the positive uniaxial cross yielded by basal sections (p. 270, note), which remain dark when revolved between crossed nicols. Commonly in formless grains (granite), also with crystal outline (porphyry, etc.).

Obs. — *Quartz* is an essential component of certain igneous rocks, as granite, granite-porphyry, quartz-porphyry and rhyolite in the granite group; in such rocks it is commonly in formless grains or masses filling the interstices between the feldspar, as the last product of crystallization. Further it is an essential constituent in quartz-diorite, quartz-diorite porphyry and dacites in the diorite group; in the porphyries frequently in distinct crystals. It occurs also as an accessory in other feldspathic igneous rocks, such as syenite and trachyte. Among the metamorphic rocks it is an essential component of certain varieties of gneiss, of quartzite, etc. It forms the mass of common sandstone. It occurs as the vein-stone in various rocks, and forms a large part of mineral veins; as a foreign mineral in some limestones, etc., making geodes of crystals, or of chalcedony, agate, carnelian, etc.; as embedded nodules or masses in various limestones, constituting the flint of the Chalk formation, the hornstone of other limestones — these nodules sometimes becoming continuous layers; as masses of jasper occasionally in limestone. It is the principal material of the pebbles of gravel-beds, and of the sands of the seashore, and sandbeds everywhere. In graphic granite (*pegmatite*) the quartz individuals are arranged in parallel position in feldspar, the angular particles resembling written characters. The quartz grains in a fragmental sandstone are often found to have undergone a secondary growth by the deposition of crystallized silica with like orientation to the original nucleus. From a general study of the chemical and mineralogical character of the rocks of the earth's crust it has been estimated that quartz forms about twelve per cent of their constituents.

Switzerland; Dauphiné, France; Piedmont, Italy; the Carrara quarries, Italy; and numerous other foreign localities afford fine specimens of rock crystal; also Japan, from which are cut the beautiful crystal spheres, in rare cases up to 6 inches in diameter; also interesting twin crystals from Kai, Japan; Bourg d'Oisans, Dauphiné, France. *Smoky quartz* crystals of great beauty, and often highly complex in form, occur at many points in the central Alps, also at Cairngorm, Scotland. The most beautiful *amethysts* are brought from India, Ceylon, and Persia, Nova Scotia, Brazil, Guanajuato, Mexico; inferior specimens occur in Transylvania. The finest *carnelians* and *agates* are found in Arabia, India, Brazil, Uruguay, Surinam, also formerly at Oberstein and Saxony. Scotland affords smaller but handsome specimens (Scotch pebbles). The banks of the Nile afford the Egyptian jasper; the striped jasper is met with in Siberia, Saxony, and Devonshire.

In N. Y., quartz crystals are abundant in Herkimer Co., at Middleville, Little Falls, etc., loose in cavities in the Calciferous sand-rock, or embedded in loose earth. Fine quartzoids, at the beds of hematite in Fowler, Herman, and Edwards, St. Lawrence Co., also at Antwerp, Jefferson Co. On the banks of Laidlaw Lake, Rossie, large implanted crystals; at Ellenville lead mine, Ulster Co., in fine groups. At Paris, Me., handsome crystals of brown or smoky quartz. Beautiful colorless crystals occur at Hot Springs, Ark. Alexander Co., N. C., has afforded great numbers of highly complex crystals, with rare modifications. Fine crystals of smoky quartz come from the granite of the Pike's Peak region, Col. Geodes of quartz crystals, also enclosing calcite, sphalerite, etc., are common in the Keokuk limestone of the west.

Rose quartz occurs at Hebron, Albany, Paris, Me.; Acworth, N. H.; Southbury, Conn.; Custer Co., S. D. *Amethyst*, in trap, at Keweenaw Point, Lake Superior; Specimen Mt., Yellowstone Park; Jefferson Co., Mon.; in Pa., at East Bradford, Chester, and Providence (one fine crystal over 7 lbs. in weight), in Chester Co.; at the Prince vein, Lake Superior; large crystals, near Greensboro, N. C.; crystallized green quartz, in talc, at Providence, Delaware Co., Pa. *Chalcedony* and *agates* abundant and beautiful on northwest shore of Lake Superior. Red jasper is found on Sugar Loaf Mt., Me.; in pebbles on the banks of the Hudson at Troy, N. Y.; yellow, with chalcedony, at Chester, Mass. Agatized and jasperized wood of great beauty and variety of color is obtained from the petrified forest called Chalcedony Park, near Carrizo, Apache Co., Ariz.; also from the Yellowstone Park; near Florissant and elsewhere in Col.; Amethyst Mt., Utah; Napa Co., Cal. Moss agates from Humboldt Co., Nev., and many other points.

The word quartz is of German provincial origin. Agate is from the name of the river Achates, in Sicily, whence specimens were brought, as stated by Theophrastus.

Use. — In its various colored forms as ornamental material; for abrading purposes; manufacture of porcelain, of glass; as wood filler; in paints, scouring soaps, etc.; as sand in mortars and cements; as quartzite, sandstone, etc., for building stone, etc.; as an acid flux in certain smelting operations.

QUARTZINE is a name which has been given to a form of silica which is present in chalcedony and is inferred to be triclinic in crystalline structure. *Lutecite* belongs here.

TRIDYMITE.

Hexagonal or pseudo-hexagonal. Axis $c = 1{\cdot}6530$. Crystals usually minute, thin tabular $\|$ $c(0001)$; often in twins; also united in fan-shaped groups.

Cleavage: prismatic, not distinct; parting $\|$ c, sometimes observed. Fracture conchoidal. Brittle. H. = 7. G. = 2·28–2·33. Luster vitreous, on c pearly. Colorless to white. Transparent. Optically +. $\omega = 1{\cdot}477$. $\epsilon = 1{\cdot}479$. Often exhibits anomalous refraction phenomena.

Comp. — Pure silica, SiO_2, like quartz.

Tridymite is formed above 800° C. See further under Quartz, p. 403.

Pyr., etc. — Like quartz, but soluble in boiling sodium carbonate.

Obs. — Occurs chiefly in acidic volcanic rocks, rhyolite, trachyte, andesite, liparite, less often in dolerite; usually in cavities, often associated with sanidine, also hornblende, augite, hematite; sometimes in opal. First observed in crevices and druses in an augite-andesite from the Cerro San Cristobal, near Pachuca, Mexico; later proved to be rather generally distributed. Thus in trachyte of the Siebengebirge, Germany; of Euganean Hills in northern Italy; Puy Capucin (Mont-Dore) in Central France, etc. In the ejected masses from Vesuvius consisting chiefly of sanidine. In the lavas of Mt. Etna, Sicily, and Mt. Pelée, Martinique. From Kibōsan, Prov. Higo, Japan. With quartz, feldspar, fayalite in lithophyses of Obsidian cliff, Yellowstone Park. In the andesite of Mt. Rainier, Washington.

Named from *τριδυμος*, *threefold*, in allusion to the common occurrence in trillings.

Asmanite. A form of silica found in the meteoric iron of Breitenbach, in very minute grains, probably identical with tridymite; by some referred to the orthorhombic system.

Cristobalite. Christobalite. Silica in white octahedrons (pseudo-isometric?). G. = 2·27. n = 1·486. With tridymite in andesite of the Cerro S. Cristobal, Pachuca, Mexico. Also noted in lava at Mayen, Germany, and in meteorites. For thermal relations to quartz and tridymite see under quartz, p. 403.

Melanophlogite. In minute cubes and spherical aggregates. Occurring with calcite and celestite implanted upon an incrustation of opaline silica over the sulphur crystals of Girgenti, Sicily. Consists of SiO_2 with 5 to 7 p. c. of SO_3, perhaps SiO_2 with SiS_2. The mineral turns black superficially when heated B.B.

OPAL.

Amorphous. Massive; sometimes small reniform, stalactitic, or large tuberose. Also earthy.

H. = 5·5–6·5. G. = 1·9–2·3; when pure 2·1–2·2. Luster vitreous, frequently subvitreous; often inclining to resinous, and sometimes to pearly. Color white, yellow, red, brown, green, gray, blue, generally pale; dark colors arise from foreign admixtures; sometimes a rich play of colors, or different colors by refracted and reflected light. Streak white. Transparent to nearly opaque. n = 1·44–1·45.

Often shows double refraction similar to that observed in colloidal substances due to tension. The cause of the play of color in the precious opal was investigated by Brewster, who ascribed it to the presence of microscopic cavities. Behrends, however, has given a monograph on the subject (Ber. Ak. Wien, **64** (1), 1871), and has shown that this explanation is incorrect; he refers the colors to thin curved lamellæ of opal whose refractive power may differ by 0·1 from that of the mass. These are conceived to have been originally formed in parallel position, but have been changed, bent, and finally cracked and broken in the solidification of the groundmass.

Comp. — Silica, like quartz, with a varying amount of water, $SiO_2.nH_2O$. The water is sometimes regarded as non-essential.

The opal condition is one of lower degrees of hardness and specific gravity, and, as generally believed, of incapability of crystallization. The water present varies from 2 to 13 p. c. or more, but mostly from 3 to 9 p. c. Small quantities of ferric oxide, alumina, lime, magnesia, and alkalies are usually present as impurities.

Var. — *Precious Opal.* — Exhibits a play of delicate colors.

Fire-opal. — Hyacinth-red to honey-yellow colors, with fire-like reflections, somewhat irised on turning.

Girasol. — Bluish white, translucent, with reddish reflections in a bright light.

Common Opal. — In part translucent; (*a*) *milk-opal*, milk-white to greenish, yellowish, bluish; (*b*) *Resin-opal*, wax-, honey- to ocher-yellow, with a resinous luster; (*c*) dull olive-green and mountain-green; (*d*) brick-red. Includes *Semiopal;* (*e*) *Hydrophane*, a variety which becomes more translucent or transparent in water.

Cacholong. — Opaque, bluish white, porcelain-white, pale yellowish or reddish.

Opal-agate. — Agate-like in structure, but consisting of opal of different shades of color.

Menilite. — In concretionary forms; opaque, dull grayish.

Jasp-opal. Opal-jasper. — Opal containing some yellow iron oxide and other impurities, and having the color of yellow jasper, with the luster of common opal.

Wood-opal. — Wood petrified by opal.

Hyalite. Muller's Glass. — Clear as glass and colorless, constituting globular concretions, and crusts with a globular or botryoidal surface; also passing into translucent, and whitish. Less readily dissolved in caustic alkalies than other varieties.

Schaumopal. — A porous variety from the Virunga district, German East Africa.

Fiorite, Siliceous Sinter. — Includes translucent to opaque, grayish, whitish or brownish incrustations, porous, to firm in texture; sometimes fibrous-like or filamentous, and, when so, pearly in luster (then called *Pearl-sinter*); deposited from the siliceous waters of hot springs.

Geyserite. — Constitutes concretionary deposits about the geysers of the Yellowstone Park, Iceland, and New Zealand, presenting white or grayish, porous, stalactitic, filamentous, cauliflower-like forms, often of great beauty; also compact-massive, and scaly-massive.

Float-stone. — In light porous concretionary masses, white or grayish, sometimes cavernous, rough in fracture.

Tripolite. — Formed from the siliceous shells of diatoms (hence called *diatomite*) and other microscopic species, and occurring in extensive deposits. Includes *Infusorial Earth*, or *Earthy Tripolite*, a very fine-grained earth looking often like an earthy chalk, or a clay, but harsh to the feel, and scratching glass when rubbed on it.

Pyr., etc. — Yields water. B.B. infusible, but becomes opaque. Some yellow varieties, containing iron oxide, turn red. Soluble in hydrofluoric acid somewhat more readily than quartz; also soluble in caustic alkalies, but more readily in some varieties than in others.

Obs. — Occurs filling cavities and fissures or seams in igneous rocks, as trachyte, porphyry, where it has probably resulted from the action of hot, magmatic waters upon the silicates of the rocks, the liberated silica being deposited in the cavities in the form of opal. Also in some metallic veins. Also embedded, like flint, in limestone, and sometimes, like other quartz concretions, in argillaceous beds; formed from the siliceous waters of some hot springs; often resulting from the mere accumulation, or accumulation and partial solution and solidification, of the siliceous shells of infusoria, of sponge spicules, etc., which consist essentially of opal-silica. The last mentioned is the probable source of the opal of limestones and argillaceous beds (as it is of flint in the same rocks), and of part of that in igneous rocks. It exists in most chalcedony and flint.

Precious opal occurs in porphyry at Czerwenitza, near Kashau in Hungary; at Gracias a Dios in Honduras; Queretaro in Mexico; a beautiful blue opal on Bulla Creek, Queensland; from White Cliffs, New South Wales, as filling openings in sandstone, in fossil wood, in the material of various fossil shells and bones and in aggregates of radiating pseudomorphic crystals. *Fire-opal* occurs at Zimapan in Mexico; the Faroe Islands; near San Antonio, Honduras. Gem opal, often of "black opal" type, comes from Humboldt Co., Nev. *Common opal* is abundant at Telkebánya in Hungary; near Pernstein, etc., in Moravia; in Bohemia; Stenzelberg in Siebengebirge, Germany; in Iceland. *Hyalite* occurs in amygdaloid at Schemnitz, Hungary; in clinkstone at Waltsch, Bohemia; at San Luis Potosi, Mexico; Kamloops, British Columbia.

In the United States, *hyalite* occurs sparingly in connection with the trap rock of N. J. and Conn. A water-worn specimen of fire-opal has been found on the John Davis river, in Crook Co., Ore.

Common opal is found at Cornwall, Lebanon Co., Pa.; at Aquas Calientes, Idaho Springs, Col.; a white variety at Mokelumne Hill, Calaveras Co., Cal., and on the Mt. Diablo range. Geyserite occurs in great abundance and variety in the Yellowstone region (cf. above); also siliceous sinter at Steamboat Springs, Nev.

Use. — In the colored varieties as a highly prized gem-stone.

II. Oxides of the Semi-Metals; also Molybdenum, Tungsten

Arsenolite. Arsenic trioxide, As_2O_3. In isometric octahedrons; in crusts and earthy. Colorless or white. G. = 3·7. n = 1·755. Occurs with arsenical ores.

Claudetite. Also As_2O_3, but monoclinic in form. In thin plates.

Senarmontite. Antimony trioxide. Sb_2O_3. In isometric octahedrons; in crusts and granular massive. G. = 5·3. Colorless, grayish. n = 2·087. Occurs with ores of antimony. From Algeria; South Ham, Quebec.

Valentinite. Sb_2O_3, in prismatic orthorhombic crystals. Index = 2·34. From South Ham, Quebec.

Bismite. Bismuth trioxide, Bi_2O_3. Pulverulent, earthy; color straw-yellow. From Goldfield, Nevada, in minute silvery white, pearly scales that are hexagonal, rhombohedral; optically −. Analyses of a number of so-called bismites show them to be bismuth hydroxide or other compounds.

Tellurite. Tellurium dioxide, TeO_2. In white to yellow slender prismatic crystals.

Molybdite. Molybdenum trioxide, MoO_3. In capillary tufted forms and earthy. Color straw-yellow. Analyses of molybdic ocher from various localities show it to be not the oxide but a hydrous ferric molybdate, $Fe_2O_3.3MO_3.7H_2O$. Indices, 1·78–1·90.

Tungstite. Tungsten trioxide, WO_3. Pulverulent, earthy; color yellow or yellowish green. Indices, 2·09–2·26. Analysis of tungstic ocher from Salmo, B. C., prove it to have the composition $WO_3.H_2O$; perhaps identical with *meymacite* (a hydrated tungstic oxide from Meymac, Corrèze, France).

Cervantite. $Sb_2O_3.Sb_2O_5$. In yellow to white acicular crystals; also massive, pulverulent.

Stibiconite. $H_2Sb_2O_5$. Massive, compact. Color pale yellow to yellowish white. Index, 1·83.

III. Oxides of the Metals

A. ANHYDROUS OXIDES

I. **Protoxides,** R_2O and RO.
II. **Sesquioxides,** R_2O_3.
III. **Intermediate,** $\overset{II}{R}\overset{III}{R}_2O_4$ or $RO.R_2O_3$, etc.
IV. **Dioxides,** RO_2.

The Anhydrous Oxides include, as shown above, three distinct divisions, the Protoxides, the Sesquioxides and the Dioxides. The remaining Intermediate division embraces a number of oxygen compounds which are properly to be regarded chemically as salts of certain acids (aluminates, ferrates, etc.); here is included the well-characterized SPINEL GROUP.

Among the Protoxides the only distinct group is the PERICLASE GROUP, which includes the rare species Periclase, MgO, Manganosite, MnO, and Bunsenite, NiO. All of these are isometric in crystallization.

The Sesquioxides include the well-characterized HEMATITE GROUP, R_2O_3. The Dioxides include the prominent RUTILE GROUP, RO_2. Both of these groups are further defined later.

I. Protoxides, R_2O and RO

CUPRITE. Red Copper Ore.

Isometric-plagiohedral. Commonly in octahedrons; also in cubes and dodecahedrons, often highly modified. Plagiohedral faces sometimes distinct (see p. 71). At times in capillary crystals. Also massive, granular; sometimes earthy.

Cleavage: *o*(111) interrupted. Fracture conchoidal, uneven. Brittle. H. = 3·5–4. G. = 5·85–6·15. Luster adamantine or submetallic to earthy. Color red, of various shades, particularly cochineal-red, sometimes almost black; occasionally crimson-red by transmitted light. Streak several shades of brownish red, shining. Subtransparent to subtranslucent. Refractive index, $n = 2·849$.

Var. — 1. *Ordinary.* (*a*) Crystallized; commonly in octahedrons, dodecahedrons, cubes, and intermediate forms; the crystals often with a crust of malachite; (*b*) massive.

2. *Capillary; Chalcotrichite.* Plush Copper Ore. In capillary or acicular crystallizations, which are sometimes cubes elongated in the direction of the cubic axis.

3. *Earthy; Tile Ore.* Brick-red or reddish brown and earthy, often mixed with red oxide of iron; sometimes nearly black.

Comp. — Cuprous oxide, Cu_2O = Oxygen 11·2, copper 88·8 = 100.

Pyr., etc. — Unaltered in the closed tube. B.B. in the forceps fuses and colors the flame emerald-green. On charcoal first blackens, then fuses, and is reduced to metallic copper. With the fluxes gives reactions for copper. Soluble in concentrated hydrochloric acid, and a strong solution when cooled and diluted with cold water yields a heavy, white precipitate of cuprous chloride.

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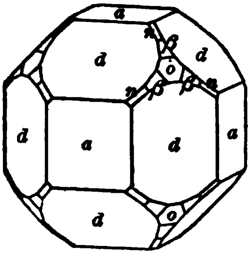

Arizona

Diff. — Distinguished from hematite by inferior hardness, but is harder than cinnabar and proustite and differs from them in the color of the streak; reactions for copper, B.B., are conclusive.

Micro. — In polished sections shows white with shining surface, usually pitted. With oblique illumination, transparent deep red. With HNO_3 instantly plated with metallic copper which blackens and dissolves. On drying a thin film of copper remains. With HCl darkens and is coated with white, seen by oblique light.

Obs. — Cuprite is a mineral of secondary origin. It is often formed as a furnace product and has been noted as a coating upon ancient copper or bronze objects. Occurs at Kamsdorf in Thuringia; in Cornwall, in fine crystals, at Wheal Gorland and other mines; in Devonshire near Tavistock; in isolated crystals, more or less altered to malachite, at Chessy, near Lyons, France; in the Ural Mts.; South Australia; also abundant in Chile, Peru, Bolivia.

In the United States observed at Somerville, etc., N. J.; at Cornwall, Lebanon Co., Pa.; in the Lake Superior region. From Ariz. with malachite, limonite, etc., at the Copper Queen mine, Bisbee, sometimes in fine crystals; beautiful *chalcotrichite* at Morenci; at Clifton, Graham Co., in crystals, and massive.

Use.— An ore of copper.

Ice. H_2O. Hexagonal. Familiarly known in six-rayed snow crystals; also coating ponds in winter, further as glaciers and icebergs.

Periclase Group

Periclase. Magnesia, MgO. In cubes or octahedrons, and in grains. Cleavage cubic. H. = 6. G. = 3·67–3·90. n = 1·74. Artif.—Crystallized from a melt containing magnesium chloride and silica. Occurs in white limestone at Mte. Somma, Vesuvius; at the Kitteln manganese mine, Nordmark, Sweden.

Manganosite. Manganese protoxide, MnO. In isometric octahedrons. Cleavage cubic. H. = 5–6. G. = 5·18. n = 2·18. Color emerald-green, becoming black on exposure. From Långban and Nordmark, Sweden; Franklin Furnace, N. J.

Bunsenite. Nickel protoxide, NiO. In green octahedrons. From Johanngeorgenstadt, Germany.

Cadmium oxide. Isometric. In minute octahedrons. Forms a thin coating of black color and brilliant metallic luster upon calamine from Monte Poni, Sardinia. Also formed artificially.

ZINCITE. Red Oxide of Zinc.

Hexagonal-hemimorphic. Axis c = 1·5870. Natural crystals rare (Fig. 44, p. 22); usually foliated massive, or in coarse particles and grains; also with granular structure.

Cleavage: *c*(0001) perfect; prismatic, sometimes distinct. Fracture subconchoidal. Brittle. H. = 4–4·5. G. = 5·43–5·7. Luster subadamantine. Streak orange-yellow. Color deep red, also orange-yellow. Translucent to subtranslucent. Optically +.

Comp. — Zinc oxide, ZnO = Oxygen 19·7, zinc 80·3 = 100. Manganese protoxide is sometimes present.

Pyr., etc. — B.B. infusible; with the fluxes, on the platinum wire, gives reactions for manganese, and on charcoal in R.F. gives a coating of zinc oxide, yellow while hot, and white on cooling. The coating, moistened with cobalt solution and treated in O.F., assumes a green color. Soluble in acids.

Diff. — Characterized by its color, particularly that of the streak; by cleavage; by reactions B.B.

Artif. — Zincite is often formed as a furnace product. It is also produced when zinc chloride and water vapor act upon lime at red heat.

Obs. — Occurs with franklinite and willemite, at Sterling Hill near Ogdensburg, and at Mine Hill, Franklin Furnace, Sussex Co., N. J., sometimes in lamellar masses in pink calcite. Has been reported from Poland. A not uncommon furnace product.

Use. — An ore of zinc.

Massicot. Lead monoxide, PbO. Massive, scaly or earthy. Color yellow, reddish. Probably orthorhombic. Index, 1·735. Optically −.

Tenorite. Cupric oxide, CuO. In minute black scales with metallic luster; from Vesuvius. Also black earthy massive (*melaconite*); occurring with ores of copper as at Ducktown, Tenn., and Keweenaw Point, Lake Superior. Pitchy black material associated with cuprite, chrysocolla and malachite from Bisbee, Ariz., has been called *melanochalcite*.

Paramelaconite is essentially cupric oxide, CuO, occurring in black pyramidal crystals referred to the tetragonal system. From the Copper Queen mine, Bisbee, Ariz.

Montroydite. HgO. Orthorhombic. In minute highly modified crystals. H. = 1·5–2. Color and streak orange-red. Index, 2·55. Volatile. Found at Terlingua, Tex.

Hematite Group. R_2O_3. Rhombohedral

		rr'	c
Corundum	Al_2O_3	93° 56′	1·3630
Hematite	Fe_2O_3	94° 0′	1·3656
Ilmenite	$(Fe,Mg)O.TiO_2$ Tri-rhombohedral	94° 29′	1·3846
Pyrophanite	$MnO.TiO_2$ "	94° 5½′	1·3692

The HEMATITE GROUP embraces the sesquioxides of aluminium and iron. These compounds crystallize in the rhombohedral class, hexagonal system, with a fundamental rhombohedron differing but little in angle from a cube. Both the minerals belonging here, Hematite and Corundum, are *hard*.

To these species the titanates of iron (and magnesium) and manganese, Ilmenite and Pyrophanite, are closely related in form though belonging to the tri-rhombohedral class (phenacite type); in other words, the relation between hematite and ilmenite may be regarded as analogous to that between calcite and dolomite. It is to be noted, further, that hematite often contains titanium, and an artificial isomorphous compound, Ti_2O_3, has been described. Hence the ground for writing the formula of ilmenite $(Fe,Ti)_2O_3$, as is done by some authors. It is shown by Penfield, however, that the formula $(Fe,Mg)TiO_3$ is more correct.

CORUNDUM.

Rhombohedral. Axis $c = 1·3630$.

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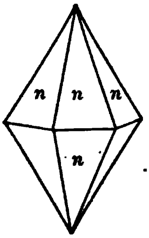

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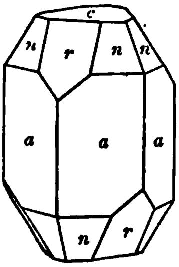

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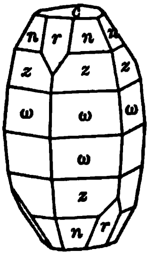

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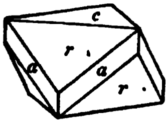

cr, $0001 \wedge 10\bar{1}1 = 57° 34'$.
cn, $0001 \wedge 22\bar{4}3 = 6\bar{1}° 11'$.
rr′ $10\bar{1}1 \wedge \bar{1}101 = 93° 56'$.
nn′, $22\bar{4}3 \wedge \bar{2}4\bar{2}3 = 51° 58'$.
vv′, $44\bar{8}3 \wedge \bar{4}8\bar{4}3 = 57° 38'$.
zz′, $22\bar{4}1 \wedge \bar{2}4\bar{2}1 = 58° 55'$.

Twins: tw. pl. $r(10\bar{1}1)$, sometimes penetration-twins; often polysynthetic, and thus producing a laminated structure. Crystals usually rough and rounded. Also massive, with nearly rectangular parting or pseudo-cleavage; granular, coarse or fine.

Parting: $c(0001)$, sometimes perfect, but interrupted; also $r(10\bar{1}1)$ due to twinning, often prominent; $a(11\bar{2}0)$ less distinct. Fracture uneven to conchoidal. Brittle, when compact very tough. H. = 9. G. = 3·95–4·10. Luster adamantine to vitreous; on *c* sometimes pearly. Occasionally showing asterism. Color blue, red, yellow, brown, gray, and nearly white; streak uncolored. Pleochroic in deeply colored varieties. Transparent to translucent. Normally uniaxial, negative; for sapphire $\omega = 1·7676$ to $1·7682$ and $\epsilon = 1·7594$ to $1·7598$. Often abnormally biaxial.

Var. — There are three subdivisions of the species prominently recognized in the arts, but differing only in purity and state of crystallization or structure.

VAR. 1. SAPPHIRE, RUBY. — Includes the purer kinds of fine colors, transparent to translucent, useful as gems. Stones are named according to their colors: *Sapphire* blue; true *Ruby*, or *Oriental Ruby*, red; *Oriental Topaz*, yellow; *Oriental Emerald*, green; *Oriental Amethyst*, purple. The term *sapphire* is also often used as a general term to indicate corundum gems of any color except red. A variety having a stellate opalescence when viewed in the direction of the vertical axis of the crystal is the *Asteriated* Sapphire or Star Sapphire.

2. CORUNDUM. — Includes the kinds of dark or dull colors and not transparent, colors light blue to gray, brown, and black. The original *adamantine spar* from India has a dark grayish smoky brown tint, but greenish or bluish by transmitted light, when translucent.

3. EMERY. — Includes granular corundum, of black or grayish black color, and contains magnetite or hematite intimately mixed. Sometimes associated with iron spinel or hercynite. Feels and looks much like a black fine-grained iron ore, which it was long considered to be. There are gradations from the evenly fine-grained emery to kinds in which the corundum is in distinct crystals.

Comp. — Alumina, Al_2O_3 = Oxygen 47·1, aluminium 52·9 = 100. The crystallized varieties are essentially pure; analyses of emery show more or less impurity, chiefly magnetite.

Artif. — Crystallized corundum has been produced artificially in a number of different ways. Alumina dissolved in molten sodium sulphide, in a fused mixture of a fluoride and potassium carbonate or in fused lead oxide, will separate out as crystallized corundum.

Gem material has been produced in this way, colored red, with a chromium salt, or blue by cobalt. Crystallized material can also be produced by fusing alumina in an electric arc. The artificial abrasive, *alundum,* is made by heating bauxite to 5000°–6000° in an electric furnace. Pear-shaped drops of gem material are made by fusing together small fragments of natural or artificial stones. Gems cut from them are known as "reconstructed" stones and have the crystalline and other physical properties of the natural mineral.

Pyr., etc. — B.B. unaltered; slowly dissolved in borax and salt of phosphorus to a clear glass, which is colorless when free from iron; not acted upon by soda. The finely pulverized mineral, after long heating with cobalt solution, gives a beautiful blue color. Not acted upon by acids, but converted into a soluble compound by fusion with potassium bisulphate.

Diff. — Characterized by its hardness (scratching quartz and topaz), by its adamantine luster, high specific gravity and infusibility. The massive variety with rhombohedral parting resembles cleavable feldspar but is much harder and denser.

Micro. — In thin sections appears nearly colorless with high relief and low interference colors.

Obs. — Usually occurs in crystalline rocks, as granular limestone or dolomite, gneiss, granite, mica slate, chlorite slate. The associated minerals often include some species of the chlorite group, as prochlorite, corundophilite, margarite, also tourmaline, spinel, cyanite, diaspore, and a series of aluminous minerals, in part produced from its alteration. Occasionally found as an original constituent of igneous rocks containing high percentages of alumina. In the Ural Mts. are found an anorthite rock containing nearly 60 per cent of corundum, a corundum syenite with 18 per cent, and a pegmatite with 35 per cent. A corundum anorthosite and corundum syenites are found in Canada. Important deposits of corundum in North Carolina and Georgia are associated with dunite rocks. Rarely observed as a contact-mineral. The fine sapphires are usually obtained from the beds of rivers, either in modified hexagonal prisms or in rolled masses, accompanied by grains of magnetite, and several kinds of gems, as spinel, etc. The emery of Asia Minor occurs in granular limestone.

The best rubies come from the mines in Upper Burma, north of Mandalay, in an area covering 25 to 30 square miles, of which Mogok is the center. The rubies occur *in situ* in crystalline limestone, also in the soil of the hillsides and in gem-bearing gravels of the Irrawaddy River. Blue sapphires are brought from Ceylon from the Ratnapura and Rakwena districts, often as rolled pebbles, also as well-preserved crystals. Corundum occurs in the Carnatic on the Malabar coast, on the Chantibun hills in Siam, and elsewhere in the East Indies; also near Canton, China; from Naegi, Mino, Japan. At St. Gothard, Switzerland, it occurs of a red or blue tinge in dolomite, and near Mozzo in Piedmont, Italy, in white compact feldspar. Adamantine spar is met with in large, coarse, hexagonal pyramids in Gellivara, Sweden. Other localities are in Bohemia, near Petschau, in Russia, in the Ilmen mountains, not far from Miask and in the gold-washings northeast of Zlatoust. Corundum, sapphires, and less often rubies occur in rolled pebbles in the diamond gravels on the Cudgegong river, at Mudgee and other points in New South Wales. Emery is found in large bowlders at Naxos, Nicaria, and Samos of the Grecian islands; also in Asia Minor, 12 m. E. of Ephesus, near Gumuchdagh and near Smyrna, associated with margarite, chloritoid, pyrite.

In North America, in Mass., at Chester, with magnetite, diaspore, ripidolite, margarite, etc., was mined for use as emery. In Conn. near Litchfield. In N. Y., at Warwick, bluish and pink, with spinel; Amity, in granular limestone; emery with magnetite and green spinel (hercynite) in Westchester Co., near Cruger's Station, and elsewhere. In N. J., at Newton, blue crystals in granular limestone; at Vernon, at Sparta and elsewhere in Sussex Co. In Pa., in Delaware Co., in Aston, near Village Green, in large crystals; at Mineral Hill, in loose crystals; in Chester Co., at Unionville, abundant in crystals; in large crystals loose in the soil at Shimersville, Lehigh Co. In Va., in the mica schists of Bull Mt., Patrick Co.

Common at many points along a belt extending from Virginia across western North and South Carolina and Georgia to Dudleyville, Alabama; especially in Madison, Buncombe, Haywood, Jackson, Macon, Clay, and Gaston counties in N. C. The localities at which most work has been done are the Culsagee mine, Corundum hill, near Franklin, Macon Co., N. C., and 26 miles S. E. of this, at Laurel Creek, Ga. The corundum occurs in beds in chrysolite (and serpentine) and hornblendic gneiss, associated with a species of the chlorite group, also spinel, etc., and here as elsewhere with many minerals resulting from its alteration. Some fine rubies have been found. Fine pink crystals of corundum occur at Hiawassee, Towns Co., Ga. In Col., small blue crystals occur in mica schist near Salida, Chaffee Co. Gem sapphires are found near Helena, Mon., in gold-washings and in bars in the Missouri river, especially the Eldorado bar; at Yogo Gulch on the Judith river and at other points in the state. These latter occur embedded in an igneous dike that cuts through the limestone formation. In Cal., in Los Angeles Co., in the drift of San Francisqueto Pass. In Canada, at Burgess, Ontario, red and blue crystals; in a syenite from Renfrew Co., Ontario.

Use. — Clear varieties of corundum form valuable gem stones as noted above. Also formerly largely used as an abrasive; at present various artificial abrasives are mostly used instead.

HEMATITE.

Rhombohedral. Axis $c = 1{\cdot}3656$.

cr, $0001 \wedge 10\bar{1}1 = 57°\ 37'$.
rr', $10\bar{1}1 \wedge \bar{1}101 = 94°\ 0'$.
dd', $01\bar{1}2 \wedge \bar{1}012 = 64°\ 51'$.
uu', $10\bar{1}4 \wedge \bar{1}104 = 37°\ 2'$.
nn', $2\bar{2}43 \wedge \bar{2}4\bar{2}3 = 51°\ 59'$.
cn, $0001 \wedge 2\bar{2}43 = 61°\ 13'$.

Twins: tw. pl. (1) *c*(0001), penetration-twins; (2) *r*$(01\bar{1}2)$, less common, usually as polysynthetic twinning lamellæ, producing a fine striation on *c*(0001), and giving rise to a distinct parting or pseudo-cleavage ‖ *r*$(10\bar{1}1)$. Crystals often thick to thin tabular ‖ *c*, and grouped in parallel position or in rosettes; *c* faces striated ‖ edge *c*/*d* $(01\bar{1}2)$ and other forms due to oscillatory combination; also in cube-like rhombohedrons; rhombohedral faces *u*$(10\bar{1}4)$ horizontally striated and often rounded over in convex forms. Also columnar to granular, botryoidal, and stalactitic shapes; also lamellar, laminæ joined parallel to *c*, and variously bent, thick or thin; also granular, friable, earthy or compact.

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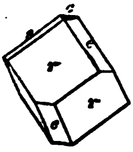

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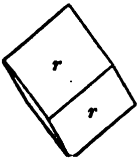

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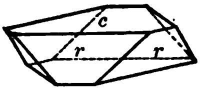

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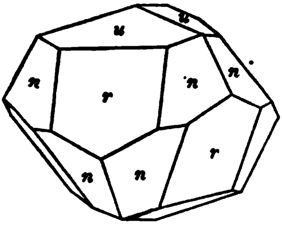

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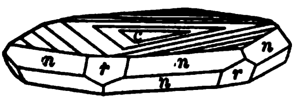


703

Parting: *c*(0001), due to lamellar structure; also *r*$(10\bar{1}1)$, caused by twinning. Fracture subconchoidal to uneven. Brittle in compact forms; elastic in thin laminæ; soft and unctuous in some loosely adherent scaly varieties. H. = 5·5–6·5. G. = 4·9–5·3; of crystals mostly 5·20–5·25; of some compact varieties, as low as 4·2. Luster metallic and occasionally splendent; sometimes dull. Color dark steel-gray or iron-black; in very thin particles blood-red by transmitted light; when earthy, red. Streak cherry-red or reddish brown. Opaque, except when in very thin laminæ.

Var. 1. *Specular.* Luster metallic, and crystals often splendent, whence the name *specular iron.* When the structure is foliated or micaceous, the ore is called *micaceous* hematite: some of the micaceous varieties are soft and unctuous. Some varieties are magnetic, but probably from admixed magnetite (Arts. **441, 443**).

the form of sand at Menaccan, Cornwall (*menaccanite*); Gastein in Tyrol (*kibdelophane*); Binnental, Switzerland. One of the most remarkable is at Kragerö, Norway, where it occurs in veins or bed; in diorite, which sometimes afford crystals weighing over 16 pounds. Others are Egersund, Arendal, Snarum in Norway; St. Gothard, Switzerland, etc.

Fine crystals, sometimes an inch in diameter, occur in Warwick, Amity, and Monroe, Orange Co., N. Y.; Litchfield, Conn. (*washingtonite*). Crystals from Chester and Quincy, Mass. Vast deposits or beds of titanic ore occur at Bay St. Paul in Quebec, Canada, in syenite; also in the Seignory of St. Francis, Beauce Co. Grains are found in the gold sand of California.

The titanic iron of massive rocks is extensively altered to a dull white opaque substance, called *leucoxene* by Gümbel. This for the most part is to be identified with titanite.

Senaite. $(Fe,Mn,Pb)O.TiO_2$. Tri-rhombohedral. H. = 6. G. = 5·3. Color black. Streak brownish black. Found in the diamond-bearing sands of Diamantina, Brazil.

Arizonite. $Fe_2O_3.3TiO_2$. Monoclinic? Crystal faces rough. H. = 5·5. G. = 4·25. Color dark steel-gray. Streak brown. Decomposed by hot concentrated sulphuric acid. Found with gadolinite, 25 miles southeast of Hackberry, Ariz.

Pyrophanite. Manganese titanate, $MnTiO_3$. In thin tabular rhombohedral crystals and scales, near ilmenite in form (p. 417). H. = 5. G. = 4·537. Luster vitreous to submetallic. Color deep blood-red. Streak ocher-yellow. From the Harstig mine, Pajsberg, Sweden.

SITAPARITE. $9Mn_2O_3.4Fe_2O_3.MnO_2.3CaO$. Not crystallized. Good cleavage. H. = 7. G. = 5·0. Color deep bronze. Streak black. Weakly magnetic. Found at Sitapár, District Chhindwára, India.

VREDENBURGITE. $3Mn_3O_4.2Fe_2O_3$. Cleavage parallel to octahedron or tetragonal pyramid. H. = 6·5. G. = 4·8. Color bronze to dark steel-gray. Streak dark brown. Strongly magnetic. Completely soluble in acids. Found at Beldóngri, District Nágpur and at Gravidi, District Vizagapatam, India.

III. Intermediate Oxides

The species here included are retained among the oxides, although chemically considered they are properly oxygen-salts, aluminates, ferrates, manganates, etc., and hence in a strict classification to be placed in section 5 of the Oxygen-salts. The one well-characterized group is the Spinel Group.

Spinel Group.	$\overset{II}{R}\overset{III}{R}_2O_4$ or $\overset{II}{R}O.\overset{III}{R}_2O_3$. Isometric
Spinel	$MgO.Al_2O_3$
Ceylonite	$(Mg,Fe)O.Al_2O_3$
Chlorospinel	$MgO.(Al,Fe)_2O_3$
Picotite	$(Mg,Fe)O.(Al,Cr)_2O_3$
Hercynite	$FeO.Al_2O_3$
Gahnite (Automolite)	$ZnO.Al_2O_3$
Dysluite	$(Zn,Fe,Mn)O.(Al,Fe)_2O_3$
Kreittonite	$(Zn,Fe,Mg)O.(Al,Fe)_2O_3$
Magnetite	$FeO.Fe_2O_3$
	$(Fe,Mg)O.Fe_2O_3$
Magnesioferrite	$MgO.Fe_2O_3$
Franklinite	$(Fe,Zn,Mn)O.(Fe,Mn)_2O_3$
Jacobsite	$(Mn,Mg)O.(Fe,Mn)_2O_3$
Chromite	$FeO.Cr_2O_3$
	$(Fe,Mg)O.(Cr,Fe)_2O_3$

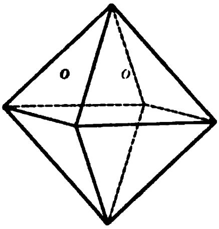
The species of the Spinel Group are characterized by isometric crystallization, and, further, the octahedron is throughout the common form. All of the species are *hard;* those with nonmetallic luster up to 7·5–8, the others from 5·5 to 6·5.

SPINEL.

Isometric. Usually in octahedrons, sometimes with dodecahedral truncations, rarely cubic. Twins: tw. pl. and comp. face *o*(111) common (Fig. 707), hence often called *spinel-twins;* also repeated and polysynthetic, producing tw. lamellæ.

Cleavage: *o*(111) imperfect. Fracture conchoidal. Brittle. H. = 8. G. = 3·5–4·1. Luster vitreous; splendent to nearly dull. Color red of various shades, passing into blue, green, yellow, brown and black; occasionally almost white. Streak white. Transparent to nearly opaque. Refractive index: $n = 1{\cdot}7155$.

706



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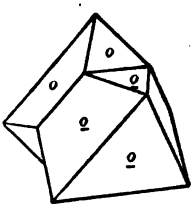


Comp. — Magnesium aluminate, $MgAl_2O_4$ or $MgO.Al_2O_3$ = Alumina 71·8, magnesia 28·2 = 100. The magnesium may be in part replaced by ferrous iron or manganese, and the aluminium by ferric iron and chromium.

Var. — Ruby Spinel or *Magnesia Spinel.* — Clear red or reddish; transparent to translucent; sometimes subtranslucent. G. = 3·63–3·71. Composition normal, with little or no iron, and sometimes chromium oxide to which the red color has been ascribed. The varieties are: (*a*) *Spinel-Ruby,* deep red; *b*) *Balas-Ruby,* rose-red; (*c*) *Rubicelle,* yellow or orange-red; (*d*) *Almandine,* violet.

Ceylonite or *Pleonaste, Iron-Magnesia Spinel.* — Color dark green, brown to black, mostly opaque or nearly so. G. = 3·5–3·6. Contains iron replacing the magnesium and perhaps also the aluminium, hence the formula $(Mg,Fe)O.Al_2O_3$ or $(Mg,Fe)O.(Al,Fe)_2O_3$.

Chlorospinel or *Magnesia-Iron Spinel.* — Color grass green, owing to the presence of copper. G. = 3·591–3·594. Contains iron replacing the aluminium, $MgO.(Al,Fe)_2O_3$.

Picotite or *Chrome-Spinel.* — Contains chromium and also has the magnesium largely replaced by iron $(Mg,Fe)O.(Al,Cr)_2O_3$, hence lying between spinel properties and chromite. G. = 4·08. Color dark yellowish brown or greenish brown. Translucent to nearly opaque.

Pyr., etc. — B.B. alone infusible. Slowly soluble in borax, more readily in salt of phosphorus, with which it gives a reddish bead while hot, becoming faint chrome-green on cooling. Black varieties give reactions for iron with the fluxes. Soluble with difficulty in concentrated sulphuric acid. Decomposed by fusion with potassium bisulphate.

Diff. — Distinguished by its octahedral form, hardness, and infusibility; zircon has a higher specific gravity; the true ruby (p. 413) is harder and is distinguished optically; garnet is softer and fusible.

Micro. — In thin section shows light color and high relief. Isotropic.

Artif. — Artificial spinel crystals may be obtained by direct crystallization from the pure melt fused in the electric arc. They also form from melts of the oxides or fluorides of magnesium and aluminium dissolved in boric acid. The addition of chromium and iron oxides will produce various colors.

Obs. — Spinel occurs embedded in granular limestone, and with calcite in serpentine, gneiss, and allied rocks. Ruby spinel is a common associate of the true ruby. Common spinel is often associated with chondrodite. It also occupies the cavities of masses ejected from some volcanoes. Spinel (common spinel, also picotite and chromite, occurs as an accessory constituent in many basic igneous rocks especially those of the peridotite group; it is the result of the crystallization of a magma very low in silica, high in magnesia and containing alumina; since, as in many of the peridotites alkalies are absent, feldspars cannot form, and the Al_2O_3 and Cr_2O_3 (also Fe_2O_3 perhaps) are compelled to form spinel (or corundum). The serpentines which yield spinel are altered peridotites.

In Ceylon, in Siam, and other eastern countries, occurs with beautiful colors, as rolled pebbles; in upper Burma with the ruby (cf. p. 414). Pleonaste is found at Candy, in Ceylon; at Åker, in Sweden, a pale blue and pearl-gray variety in limestone; small black splendent crystals occur in the ancient ejected masses of Monte Somma, Vesuvius; also at Pargas, Finland, with chondrodite, etc.; in compact gehlenite at Monzoni, in the Fassa valley, Austria.

From Amity, N. Y., to Andover, N. J., a distance of about 30 miles, is a region of granular limestone and serpentine, in which localities of spinel abound; colors, green, black, brown, and less commonly red, along with chondrodite and other minerals. Localities are numerous about Warwick, and also at Monroe and Cornwall; Gouverneur, 2 m. N. and ¾ m. W. of Somerville, St. Lawrence Co.; green, blue, and occasionally red varieties occur at Bolton, Boxborough, etc., Mass. Franklin, N. J., affords crystals of various shades of black, blue, green, and red: Newton, Sterling, Sparta, Hamburgh and Vernon, N. J., are other localities. With the corundum of N. C. as at the Culsagee mine, near Franklin, Macon Co.; similarly at Dudleyville, Ala. Spinel ruby at Gold Bluff, Humboldt Co., Cal.

Good black spinel is found in Burgess, Ontario; a bluish spinel having a rough cubic form occurs at Wakefield, Ottawa Co.; blue with clintonite at Daillebout, Joliette Co., Quebec.

Use. — The colored transparent varieties are used as gems.

Hercynite. Iron Spinel, $FeAl_2O_4$. Isometric; massive, fine granular. H. = 7·5–8. G. = 3·91–3·95. Color black. From Ronsberg, at the eastern foot of the Böhmerwald, Bohemia. A related iron-alumina spinel, with about 9 p. c. MgO, occurs with magnetite and corundum in Cortlandt township, Westchester Co., N. Y. From the tin drift, Moorina, Tasmania.

GAHNITE. Zinc-Spinel.

Isometric. Habit octahedral, often with faces striated || edge between dodecahedron and octahedron; also less commonly in dodecahedrons and modified cubes. Twins: tw. pl. *o*(111).

Cleavage: *o*(111) indistinct. Fracture conchoidal to uneven. Brittle. H. = 7·5–8. G. = 4·0–4·6. n_{gr} = 1·82 (Finland). Luster vitreous, or somewhat greasy. Color dark green, grayish green, deep leek-green, greenish black, bluish black, yellowish, or grayish brown; streak grayish. Subtransparent to nearly opaque.

Comp. — Zinc aluminate, $ZnAl_2O_4$ = Alumina 55·7, zinc oxide 44·3 = 100. The zinc is sometimes replaced by manganese or ferrous iron, the aluminium by ferric iron.

Var. — AUTOMOLITE, or *Zinc Gahnite*. — $ZnAl_2O_4$, with sometimes a little iron. G. = 4·1–4·6. Colors as above given.

DYSLUITE, or *Zinc-Manganese-Iron Gahnite*. — $(Zn,Fe,Mn)O.(Al,Fe)_2O_3$. Color yellowish brown or grayish brown. G. = 4–4·6.

KREITTONITE, or *Zinc-Iron Gahnite*. — $(Zn,Fe,Mg)O.(Al,Fe)_2O_3$. In crystals, and granular massive. H. = 7–8. G. = 4·48–4·89. Color velvet-black to greenish black; powder grayish green. Opaque.

Pyr., etc. — Gives a coating of zinc oxide when treated with a mixture of borax and soda on charcoal; otherwise like spinel.

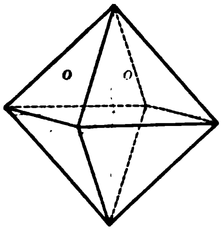
Obs. — Occurs at Falun and Färila parish, Helsingland, Sweden (*automolite*); Träskböle, Finland; at Tiriola, Calabria, Italy; at Bodenmais, Bavaria (*kreittonite*); Minas Geraes, Brazil; Ambatofisikely, Madagascar. In the United States, at Franklin Furnace, N. J., with franklinite and willemite; also at Sterling Hill, N. J. (*dysluite*); with pyrite at Rowe, Mass.; at a feldspar quarry in Delaware Co., Pa.; sparingly at the Deake mica mine, Mitchell Co., N. C.; at the Canton Mine, Ga.; with galena, chalcopyrite, pyrite at the Cotopaxi mine, Chaffee Co., Col. In Canada at Raglan, Renfrew Co., Ontario.

Named after the Swedish chemist Gahn. The name *Automolite*, of Ekeberg, is from *αὐτόμολος, a deserter*, alluding to the fact of the zinc occurring in an unexpected place.

MAGNETITE. Magnetic Iron Ore.

Isometric. Most commonly in octahedrons, also in dodecahedrons with faces striated || edge between dodecahedron and octahedron (Fig. 710); in dendrites between plates of mica; crystals sometimes highly modified; cubic forms rare. Twins: tw. pl. *o*(111), sometimes as polysynthetic twinning lamellæ, producing striations on an octahedral face and often a pseudo-cleavage (Fig. 474, p. 176). Massive with laminated structure; granular, coarse or fine; impalpable.

708



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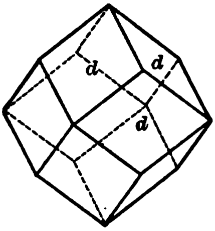

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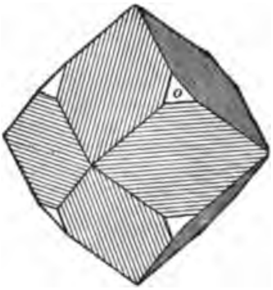
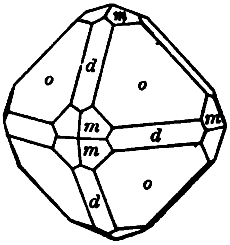


Cleavage not distinct; parting octahedral, often highly developed. Fracture subconchoidal to uneven. Brittle. H. = 5·5–6·5. G. = 5·168–5·180, crystals. Luster metallic and splendent to submetallic and rather dull. Color iron-black. Streak black. Opaque, but in thin dendrites in mica nearly transparent and pale brown to black. Strongly magnetic; sometimes possessing polarity (lodestone).

Comp. — $\overset{II}{Fe}\overset{III}{Fe_2}O_4$ or $FeO.Fe_2O_3$ = Iron sesquioxide 69.0, iron protoxide 31·0 = 100; or, Oxygen 27·6, iron 72·4 = 100. The ferrous iron sometimes replaced by magnesium, and rarely nickel; also sometimes contains titanium (up to 6 p. c. TiO_2).

711



Var. — *Ordinary.* — (*a*) In crystals. (*b*) Massive, with pseudo-cleavage, also granular, coarse or fine. (*c*) As loose sand. (*d*) Ocherous: a black earthy kind. Ordinary magnetite is attracted by a magnet but has no power of attracting particles of iron itself. The property of polarity which distinguishes the *lodestone* (less properly written loadstone) is exceptional.

Magnesian. — G. = 4·41–4·42; luster submetallic; weak magnetic; in crystals from Sparta, N. J., and elsewhere.

Manganesian. — Containing 3·8 to 6·3 p. c. manganese (*Manganmagnetite*). From Vester Silfberg, Sweden.

Pyr., etc. — B.B. very difficultly fusible. In O.F. loses its influence on the magnet. With the fluxes reacts like hematite. Soluble in hydrochloric acid and solution reacts for both ferrous and ferric iron.

Diff. — Distinguished from other members of the spinel group, as also from garnet, by its being attracted by the magnet, as well as by its high specific gravity; franklinite and chromite are only feebly magnetic (if at all), and have a brown or blackish brown streak; also, when massive, by its black streak from hematite and limonite; much harder than tetrahedrite.

Micro. — In polished sections shows white color with a shining, pitted surface. With conc. HCl slowly turns brown.

Artif. — Magnetite is frequently formed as a furnace product. It is easily formed in artificial magmas when they are low in the percentage of silica. It is formed by the breaking down of various minerals or by interreactions among minerals in processes similar to those of contact metamorphism.

Obs. — Magnetite is mostly confined to crystalline rocks, and is most abundant in metamorphic rocks, though widely distributed also in grains in eruptive rocks. It is found most abundantly in the ferro-magnesian rocks, occurring at times in large segregated masses. These are often highly titaniferous. In the Archæan rocks the beds are of immense extent, and occur under the same conditions as those of hematite. It is an ingredient in most of the massive variety of corundum called emery. The earthy magnetite is found in bogs like bog-iron ore. Occurs in meteorites, and forms the crust of meteoric irons.

Present in dendrite-like forms in the mica of many localities following the direction of the lines of the percussion-figure, and perhaps of secondary origin. A common alteration-product of minerals containing iron protoxide, *e.g.*, present in veins in the serpentine resulting from altered chrysolite.

The beds of ore at Arendal, Norway, and nearly all the celebrated iron mines of Sweden, consist of massive magnetite, as at Dannemora and the Täberg in Småland. Falun, in Sweden, and Corsica, afford octahedral crystals, embedded in chlorite slate. Splendid dodecahedral crystals occur at Nordmark in Wermland. The most powerful native magnets are found in Siberia, and in the Harz Mts., Germany; they are also obtained on the island of Elba. Other localities for the crystallized mineral are Traversella in Piedmont, Italy; Achmatovsk in the Ural Mts.; Scalotta, near Predazzo, at Rothenkopf and Wildkreuzjoch, Austrian Tyrol; the Binnental, Switzerland; Sannatake, Bufen, Japan.

In North America, it constitutes vast beds in the Archæan, in the Adirondack region, Warren, Essex, and Clinton Cos., in Northern N. Y., while in St. Lawrence Co. the iron ore is mainly hematite; fine crystals and masses showing broad parting surfaces and yielding large pseudo-crystals are obtained at Port Henry, Essex Co.; similarly in N J.; in Canada, in Hull, Greenville, Madoc, etc.; at Cornwall in Pa., and Magnet Cove, Ark. It occurs also in N. Y., in Saratoga, Herkimer, Orange, and Putnam Cos.; at the Tilly Foster iron mine, Brewster, Putnam Co., in crystals and massive accompanied by chondrodite, etc. In N. J., at Hamburg, near Franklin Furnace and elsewhere. In Pa., at Goshen, Chester Co., and at the French Creek mines; delineations forming hexagonal figures in mica at Pennsbury. Good lodestones are obtained at Magnet Cove, Ark. In Cal., in Sierra Co., abundant, massive, and in crystals; in Plumas Co.; and elsewhere. In Wash., in large deposits. In crystals from Millard Co., Utah. Fine crystals from Fiormeza, Cuba.

Named from the loc. *Magnesia* bordering on Macedonia. But Pliny favors Nicander's derivation from Magnes, who first discovered it, as the fable runs, by finding, on taking his herds to pasture, that the nails of his shoes and the iron ferrule of his staff adhered to the ground.

Use. — An important ore of iron.

FRANKLINITE.

Isometric. Habit octahedral; edges often rounded, and crystals passing into rounded grains. Massive, granular, coarse or fine to compact.

Pseudo-cleavage, or parting, octahedral, as in magnetite. Fracture conchoidal to uneven. Brittle. H. = 5·5–6·5. G. = 5·07–5·22. Luster metallic, sometimes dull. Color iron-black. Streak reddish brown or black. Opaque. Slightly magnetic.

Comp. — $(Fe,Zn,Mn)O.(Fe,Mn)_2O_3$, but varying rather widely in the relative quantities of the different metals present, while conforming to the general formula of the spinel group.

Pyr., etc.—B.B. infusible. With borax in O.F. gives a reddish amethystine bead (manganese), and in R.F. this becomes bottle-green (iron). With soda gives a bluish green manganate, and on charcoal a faint coating of zinc oxide, which is much more marked when a mixture with borax and soda is used. Soluble in hydrochloric acid, sometimes with evolution of a small amount of chlorine.

Diff. — Resembles magnetite, but is only slightly attracted by the magnet, and has a dark brown streak; it also reacts for zinc on charcoal B.B.

Obs. — In Germany occurs in cubic crystals near Eibach in Nassau; in amorphous masses at Altenberg, near Aix-la-Chapelle. Abundant at Mine Hill, Franklin Furnace, N. J., with willemite and zincite in granular limestone; also at Sterling Hill, two miles distant, associated with willemite.

Use. — An ore of zinc.

Magnesioferrite. Magnoferrite. $MgFe_2O_4$. In octahedrons. H. = 6–6·5 G. = 4·568–4·654. Luster, color, and streak as in magnetite. Strongly magnetic. Formed about the fumaroles of Vesuvius, and especially those of the eruption of 1855; also found at Mont Dore, France.

Jacobsite. (Mn,Mg)O.(Fe,Mn)$_2$O$_3$. Isometric; in distorted octahedrons. H. = 6. G. = 4·75. Color deep black. Magnetic. From Jakobsberg, in Nordmark, Wermland, and at Långban, Sweden. Reported from Bulgaria.

CHROMITE.

Isometric. In octahedrons. Commonly massive; fine granular to compact.

Fracture uneven. Brittle. H. = 5·5. G. = 4·32–4·57. Luster submetallic to metallic. Color between iron-black and brownish black, but sometimes yellowish red in very thin sections. Streak brown. Translucent to opaque. Sometimes feebly magnetic.

Comp. — FeCr$_2$O$_4$ or FeO.Cr$_2$O$_3$ = Chromium sesquioxide 68·0, iron protoxide 32·0 = 100.

The iron may be replaced by magnesium; also the chromium by aluminium and ferric iron. The varieties containing but little chromium (up to 10 p. c.) are hardly more than varieties of spinel and are classed under picotite, p. 419.

Pyr., etc. — B.B. in O.F. infusible; in R.F. slightly rounded on the edges, and becomes magnetic. With borax and salt of phosphorus gives beads which, while hot, show only a reaction for iron, but on cooling become chrome-green; the green color is heightened by fusion on charcoal with metallic tin. Not acted upon by acids, but decomposed by fusion with potassium or sodium bisulphate.

Diff. — Distinguished from magnetite by feeble magnetic properties, streak and by yielding the reaction for chromic acid with the blowpipe.

Artif. — Chromite can be prepared artificially by fusing together chromic, ferric and boric oxides.

Obs. — Occurs in peridotite rocks and the serpentines derived from them, forming veins, or in embedded masses. It is one of the earliest minerals to crystallize in a cooling magma and its large ore bodies are probably formed during the solidification of the rock by the process of magmatic differentiation. It assists in giving the variegated color to verde-antique marble. Not uncommon in meteoric irons, sometimes in nodules as in the Coahuila iron, less often in crystals (Lodran).

Occurs in the Gulsen mountains, near Kraubat in Styria; in crystals in the islands of Unst and Fetlar, in Shetland; in the province of Trondhjem in Norway; in the Department du Var in France; in Silesia and Bohemia; abundant in Asia Minor; in the Eastern and Western Ural Mts.; in New Caledonia, affording ore for commerce.

In Md. at Baltimore, in the Bare Hills, in veins or masses in serpentine; also in Montgomery Co., etc. In Pa., Chester Co., near Unionville, abundant; at Wood's Mine, near Texas, Lancaster Co., very abundant. Massive and in crystals at Hoboken, N. J., in serpentine and dolomite. In various localities in N. C. In the southwestern part of the town of New Fane, etc., Vt. A magnesian variety (*mitchellite*) from Webster, N. C. In Cal., in Monterey Co.; also Santa Clara Co., near the New Almaden mine.

Use. — An ore of chromium; used in refractory bricks for metallurgical furnace linings; as source of certain red and yellow pigments and dyes.

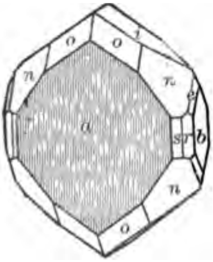
CHROMITITE. Material in minute octahedral crystals occurring in sand at Zeljin Mt., Servia, said to have composition, FeCrO$_3$.

CHRYSOBERYL. Cymophane.

Orthorhombic. Axes *a* : *b* : *c* = 0·4701 : 1 : 0·5800.

mm''', $110 \wedge 1\bar{1}0 = 50° 21'$.
ss', $120 \wedge \bar{1}20 = 93° 32'$.
xx', $101 \wedge \bar{1}01 = 101° 57'$.
ii', $011 \wedge 0\bar{1}1 = 60° 14'$.
$\rho\rho'$, $031 \wedge 0\bar{3}1 = 120° 14'$.
oo', $111 \wedge \bar{1}11 = 93° 44'$.
oo''', $111 \wedge 1\bar{1}1 = 40° 7'$.
nn', $121 \wedge \bar{1}21 = 77° 43'$.

712



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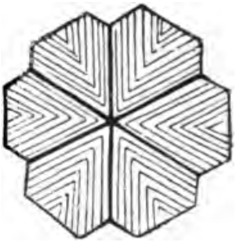


Twins: tw. pl. ρ(031), both contact- and penetration-twins; often repeated and forming pseudo-hexagonal crystals with or without re-entrant angles (Fig. 395, p. 164). Crystals generally tabular || *a*(100). Face *a* striated vertically, in twins a feather-like striation (Fig. 713).

Cleavage: *i*(011) quite distinct; *b*(010) imperfect; *a*(100) more so. Fracture uneven to conchoidal. Brittle. H. = 8·5. G. = 3·5–3·84. Luster vitreous. Color asparagus-green, grass-green, emerald-green, greenish white, and yellowish green; greenish brown; yellow; sometimes raspberry- or columbine-red by transmitted light. Streak uncolored. Transparent to translucent. Sometimes a bluish opalescence or chatoyancy, and asteriated. Pleochroic, vibrations || *Y* (= *b* axis) orange-yellow, *Z* (= *c* axis) emerald-green, *X* (= *a* axis) columbine-red. Optically +. Ax. pl. || *b*(010). Bx. ⊥ *c*(001). α = 1·747. β = 1·748. γ = 1·757. 2E = 84° 43′.

Var. 1. *Ordinary.* — Color pale green, being colored by iron; also yellow and transparent and then used as a gem.

2. *Alexandrite.* — Color emerald-green, but columbine-red by transmitted light; valued as a gem. G. = 3·644, mean of results. Supposed to be colored by chromium. Crystals often very large, and in twins, like Fig. 395, either six-sided or six-rayed.

3. *Cat's-eye.* — Color greenish and exhibiting a fine chatoyant effect; from Ceylon.

Comp. — Beryllium aluminate, $BeAl_2O_4$ or $BeO.Al_2O_3$ = Alumina 80·2, glucina 19·8 = 100.

Pyr., etc. — B.B. alone unaltered; with soda, the surface is merely rendered dull. With borax or salt of phosphorus fuses with great difficulty. Ignited with cobalt solution, the powdered mineral gives a bluish color. Not attacked by acids.

Diff. — Distinguished by its extreme hardness, greater than that of topaz; by its infusibility; also characterized by its tabular crystallization, in contrast with beryl.

Obs. — In Minas Geraes, Brazil, in rolled pebbles; from Ceylon in pebbles and crystals; at Marschendorf in Moravia; in the Ural Mts., 85 versts from Ekaterinburg, in mica slate with beryl and phenacite, the variety *alexandrite;* in the Orenburg district, southern Ural Mts., yellow; in the Mourne Mts., Ireland.

In the United States at Haddam, Conn., in granite traversing gneiss, with tourmaline, garnet, beryl; at Greenfield, near Saratoga, N. Y., with tourmaline, garnet, and apatite; has been found in crystals in the rocks of New York City; in Me. at Norway, in granite with garnet and at Stoneham, with fibrolite, at Topsham, Buckfield and Greenwood.

Chrysoberyl is from *χρύσος, golden, βήρυλλος, beryl. Cymophane,* from *κῦμα, wave,* and *φαίνω, appear,* alludes to a peculiar opalescence the crystals sometimes exhibit. *Alexandrite* is after the Czar of Russia, Alexander I.

Use. — As a gem stone; see under **Var.** above.

Hausmannite. Mn_3O_4 or $MnO. Mn_2O_3$. In tetragonal octahedrons and twins (Fig. 414, p. 167); also granular massive, particles strongly coherent. H. = 5–5·5. G. = 4·856. Luster submetallic. Color brownish black. Streak chestnut-brown. Occurs near Ilmenau in Thuringia, Germany; Ilefeld in the Harz Mts., Germany; Filipstad, Långban, Nordmark, in Sweden; from Brazil.

Coronadite. $(Mn,Pb)Mn_3O_7$. Massive with delicate fibrous structure. H. = 4. G. = 5·2. Color black. Streak brownish black. Occurs in Coronado vein of the Clifton-Morenci district, Arizona. *Hollandite* is a similar manganate of manganese, barium and ferric iron from the Káljlidongri manganese mine, Central India.

Cesàrolite. $H_2PbMn_3O_8$. In cellular masses. Color, steel-gray. H. = 4·5. G. = 5·29. From Sidi-Amer-bers-Salem, Tunis.

Minium. Pb_3O_4 or $2PbO.PbO_2$. Pulverulent, as crystalline scales. G. = 4·6. Color vivid red, mixed with yellow; streak orange-yellow. Occurs in Germany at Bleialf in the Eifel; Badenweiler in Baden, etc.

Crednerite. $Cu_3Mn_4O_9$ or $3CuO.2Mn_2O_3$. Foliated crystalline. H. = 4·5. G. = 4·9–5·1. Luster metallic. Color iron-black to steel-gray. Streak black, brownish. From Friedrichroda, Germany.

Pseudobrookite. Probably $Fe_4(TiO_4)_3$. Usually in minute orthorhombic crystals, tabular || *a*(100) and often prismatic || the macro-axis. G. = 4·4–4·98. Color dark brown to black. Streak ocher-yellow. Found with hypersthene (szaboite) in cavities of the andesite of Aranyer Berg, Transylvania, and elsewhere; on recent lava (1872) from Vesuvius; at Havredal, Bamle, Norway, embedded in kjerulfine (wagnerite) altered to apatite.

BRAUNITE.

Tetragonal. Axis *c* = 0·9850. Commonly in octahedrons, nearly isometric in angle (*pp'* 111 ∧ $1\bar{1}1$ = 70° 7'). Also massive.

Cleavage : *p*(111) perfect. Fracture uneven to subconchoidal. Brittle. H. = 6–6·5. G. = 4·75–4·82. Luster submetallic. Color and streak, dark brownish black to steel-gray.

Comp. — $3Mn_2O_3.MnSiO_3$ = Silica 10·0, manganese protoxide 11·7, manganese sesquioxide 78·3 = 100.

Pyr., etc. — B.B. infusible. With borax and salt of phosphorus gives an amethystine bead in O.F., becoming colorless in R.F. With soda gives a bluish green bead. Dissolves in hydrochloric acid leaving a residue of gelatinous silica. Marceline gelatinizes with acids.

Obs. — Occurs in veins traversing porphyry, at Oehrenstock, near Ilmenau, Thuringia, and near Ilefeld in the Harz Mts., Germany; St. Marcel in Piedmont, Italy; at Elba; at Botnedal, Upper Tellemark, in Norway; at the manganese mines of Jakobsberg, also at Långban, and at the Sjö mine, Grythyttan, Orebro, Sweden. *Marceline* (heterocline) from St. Marcel, Piedmont, is impure braunite.

Bixbyite. Essentially $FeO.MnO_2$. In black isometric crystals. H. = 6–6·5. G. = 4·945. Occurs with topaz in cavities in rhyolite; from Utah.

IV. Dioxides, RO_2.

Rutile Group. Tetragonal

		c			*c*
Cassiterite	SnO_2	0·6723	**Rutile**	TiO_2	0·6442
Polianite	MnO_2	0·6647	**Plattnerite**	PbO_2	0·6764

The RUTILE GROUP includes the dioxides of the elements tin, manganese, titanium, and lead. These compounds crystallize in the tetragonal system with closely similar angles and axial ratio; furthermore in habit and method of twinning there is much similarity between the two best known species included here. Chemically these minerals are sometimes considered as salts of their respective acids, as stannyl metastannate, $(SnO)SnO_3$, for cassiterite and titanyl metatitanate, $(TiO)TiO_3$, for rutile.

With the Rutile Group is also sometimes included Zircon. ZrO_2SiO_2; *c* = 0·6404. In this work, however, Zircon is classed among the silicates, with the allied species Thorite, $ThO_2.SiO_2$, *c* = 0·6402.

A tetragonal form, approximating closely to that of the species of the Rutile Group, belongs also to a number of other species, as Xenotime, YPO_4; Sellaite, MgF_2; Tapiolite, $Fe(Ta,Nb)_2O_6$.

It may be added that ZrO_2, as the species Baddeleyite, crystallizes in the monoclinic system.

CASSITERITE. Tin-stone, Tin Ore

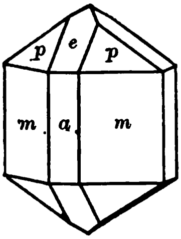
Tetragonal. Axis *c* = 0·6723.

ee', 101 ∧ 011 = 46° 28'.
ee'', 101 ∧ $\bar{1}01$ = 67° 50'.
ss', 111 ∧ $\bar{1}11$ = 58° 19'.
ss'', 111 ∧ $\bar{1}\bar{1}1$ = 87° 7'
ms, 110 ∧ 111 = 46° 27'.
zz', 321 ∧ 231 = 20° 53½'
zz^{vii}, 321 ∧ $3\bar{2}1$ = 61° 42'.

Twins common: tw. pl. *e*(101); both contact- and penetration-twins (Fig. 717); often repeated. Crystals low pyramidal; also prismatic and acutely terminated. Often in reniform shapes, structure fibrous divergent; also massive, granular or impalpable; in rolled grains.

Cleavage: *a*(100) imperfect; *s*(111) more so; *m*(110) hardly distinct. Fracture subconchoidal to uneven. Brittle. H. = 6–7. G. = 6·8–7·1. Luster adamantine, and crystals usually splendent. Color brown or black; sometimes red, gray, white, or yellow. Streak white, grayish, brownish. Nearly transparent to opaque. Optically +. Indices: $\omega = 1{\cdot}9966$, $\epsilon = 2{\cdot}0934$.

714



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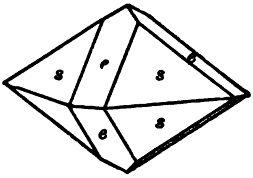

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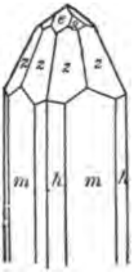

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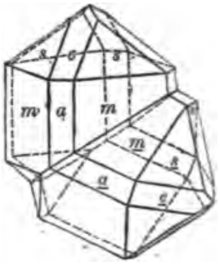


Var. — *Ordinary.* Tin-stone. In crystals and massive.

Wood-tin. In botryoidal and reniform shapes, concentric in structure, and radiated fibrous internally, although very compact, with the color brownish, of mixed shades, looking somewhat like dry wood in its colors. *Toad's-eye tin* is the same, on a smaller scale. *Stream-tin* is the ore in the state of sand, as it occurs along the beds of streams or in gravel.

Comp. — Tin dioxide, SnO_2 = Oxygen 21·4, tin 78·6 = 100. A little Ta_2O_5 is sometimes present, also Fe_2O_3.

Pyr., etc. — B.B. alone unaltered. On charcoal with soda reduced to metallic tin, and gives a white coating. With the fluxes sometimes gives reactions for iron and manganese. Only slightly acted upon by acids.

Diff. — Distinguished by its high specific gravity, hardness, infusibility, and by its yielding metallic tin B.B.; resembles some varieties of garnet, sphalerite, and black tourmaline. Specific gravity (6·5) higher than that of rutile (4); wolframite is easily fusible.

Artif. — Cassiterite has been artificially prepared by the action of aqueous vapor upon tin tetrachloride in a heated tube and by other similar methods employing heated vapors.

Obs. — Cassiterite has been noted as an original constituent of igneous rocks but usually it occurs in veins traversing granite, rhyolite, quartz porphyry, pegmatite, gneiss, mica schist, chlorite or clay schist; also in finely reticulated veins forming the ore-deposits called stockworks, or simply impregnating the enclosing rock. It is most commonly found in quartz veins traversing granite, accompanied by minerals containing boron and fluorine which indicates a pneumatolytic origin. The commonly associated minerals are quartz, wolframite, scheelite; also mica, topaz, tourmaline, apatite, fluorite; further pyrite, arsenopyrite, sphalerite; molybdenite, native bismuth, etc.

Formerly very abundant, now less so, in Cornwall, in fine crystals, and also as *wood-tin* and *stream-tin;* in Devonshire, near Tavistock and elsewhere; in pseudomorphs after feldspar at Wheal Coates, near St. Agnes, Cornwall; in fine crystals, often twins, at Schlackenwald, Graupen, Joachimstal, Zinnwald, etc., in Bohemia, and at Ehrenfriedersdorf, Altenberg, etc., in Saxony; at Limoges, France, in splendid crystals; Sweden, at Finbo; Finland, at Pitkäranta.

In the East Indies, on the Malay peninsula of Malacca and the neighboring islands, Banca, and Bilitong near Borneo. In New South Wales abundant over an area of 8500 sq. miles, also in Victoria, Queensland and Tasmania. In Bolivia in veins containing silver, lead, and bismuth; Mexico, in Durango, Guanajuato, Zacatecas, Jalisco.

In the United States, in Me., sparingly at Paris, Hebron, etc. In Mass., at Chesterfield and Goshen, rare. In N. H., at Jackson. In Va.. on Irish Creek, Rockbridge Co., with wolframite, etc. In N. C. and S. C. In Ala., in Coosa Co. In S. D., near Harney Peak and near Custer City in the Black Hills, where it has been mined. In Wy., in Crook Co.; in Mon., near Dillon. In Cal., in San Bernardino Co., at Temescal. Has been mined in the York district, Seward Peninsula, Alaska.

Use. — The most important ore of tin.

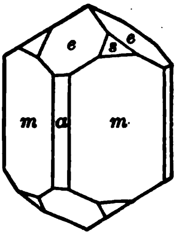
Polianite. Manganese dioxide, MnO_2. In composite parallel groupings of minute crystals; also forming the outer shell of crystals having the form of manganite. H. = 6–6·5. G. = 4·992. Luster metallic. Color light steel-gray or iron-gray. Streak black. From Platten, Bohemia. It is distinguished from pyrolusite by its hardness and its anhydrous character. Like pyrolusite it is often a pseudomorph after manganite.

RUTILE.

Tetragonal. Axis c = 0·64415.

ll^{vii}, 310 ∧ $3\bar{1}0$ = 36° 54′.
ee′, 101 ∧ 011 = 45° 2′.
ee″, 101 ∧ $\bar{1}01$ = 65° 34½′.
ss′, 111 ∧ $\bar{1}11$ = 56 25½′.
ss″, 111 ∧ $\bar{1}\bar{1}1$ = 84° 40′.
tt′, 313 ∧ 133 = 29° 6′.

718



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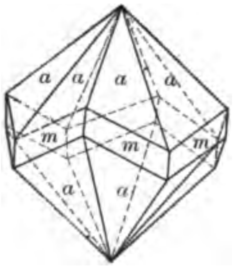

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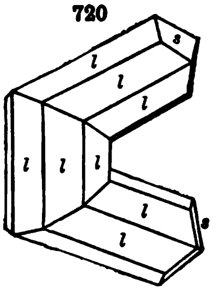
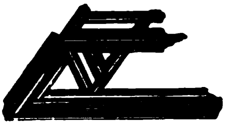


Twins: tw. pl. (1) e(101); often geniculated (Figs. 720, 721); also contact-twins of very varied habit, sometimes sixlings and eightlings (Fig. 399, p. 164; Fig. 413, p. 166). (2) v(301) rare, contact-twins (Fig. 415, p. 167). Crystals commonly prismatic, vertically striated or furrowed; often slender acicular. Occasionally compact, massive.

721



Cleavage: a(100) and m(110) distinct; s(111) in traces. Fracture subconchoidal to uneven. Brittle. H. = 6–6·5. G. = 4·18–4·25; also to 5·2. Luster metallic-adamantine. Color reddish brown, passing into red; sometimes yellowish, bluish, violet, black, rarely grass-green; by transmitted light deep red. Streak pale brown. Transparent to opaque. Optically +. Refractive indices high: ω = 2·6158, ϵ = 2·9029. Birefringence very high. Sometimes abnormally biaxial.

Comp. — Titanium dioxide, TiO_2 = Oxygen 40·0, titanium 60·0 = 100. A little iron is usually present, sometimes up to 10 p. c. While the iron present is often reported as ferric the probability is that in the unaltered mineral it existed in the ferrous state.

The formula for rutile may be written as a titanyl metatitanate $(TiO)TiO_3$ With this the ferrous titanate $FeTiO_3$ may be considered isomorphous and so account for the iron frequently present. It has been suggested that the tapiolite molecule, $FeO.Ta_2O_5$ is also isomorphous and that tapiolite belongs in the same group as rutile and cassiterite, see *ilmenorutile*, below.

Var. — *Ordinary*. Brownish red and other shades, not black. G. = 4·18–4·25. Transparent quartz (*sagenite*) is sometimes penetrated thickly with acicular or capillary crystals. Dark smoky quartz penetrated with the acicular rutile or "rutilated quartz," is the Flèches d'amour *Fr.* (or Venus hair-stone). Acicular crystals often implanted in parallel position on tabular crystals of hematite; also somewhat similarly on magnetite.

Ferriferous. (*a*) *Nigrine* is black in color, whence the name; contains up to 30 p. c. of ferrous titanate. (*b*) *Ilmenorutile* is a black variety from the Ilmen Mts., Russia; containing iron in the form of ferrous titanate, niobate and tantalate. G. = 5·14. *Strüverite* is the same mineral with greater amounts of the niobate present. (*c*) *Iserine* from Iserweise, Bohemia, formerly considered to be a variety of ilmenite is probably also a ferriferous rutile.

Pyr., etc. — B.B. infusible. With salt of phosphorus gives a colorless bead, which in R.F. assumes a violet color on cooling. Most varieties contain iron, and give a brownish yellow or red bead in R.F., the violet only appearing after treatment of the bead with metallic tin on charcoal. Insoluble in acids; made soluble by fusion with an alkali or alkaline carbonate. The solution containing an excess of acid, with the addition of tin-foil, gives a beautiful violet color when concentrated.

Diff. — Characterized by its peculiar sub-adamantine luster and brownish red color. Differs from tourmaline, vesuvianite, augite in being entirely unaltered when heated alone B.B. Specific gravity about 4, of cassiterite 6·5.

Micro. — In thin sections shows red-brown to yellow color, very high relief and high order of interference color.

Artif. — Rutile has been formed artificially by heating titanic oxide with boric oxide, with sodium tungstate, etc. Rutile, octahedrite and brookite have all been formed by heating potassium titanate and calcium chloride in a current of hydrochloric acid gas and air. Rutile is formed at the highest temperature, brookite at lower temperatures, and octahedrite at the lowest of all.

Obs. — Rutile occurs as an accessory mineral in granite, gneiss, mica schist, and syenitic rocks, and sometimes in granular limestone and dolomite; common, as a secondary product, in the form of microlites in many slates. A dike rock from Nelson Co., Va., consists essentially of rutile and apatite. It is generally found in embedded crystals, often in masses of quartz or feldspar, and frequently in acicular crystals penetrating quartz; also in phlogopite (which see), and has been observed in diamond. It has also been met with in hematite and ilmenite, rarely in chromite. It is common in grains or fragments in many auriferous sands.

Prominent localities are: Arendal and Kragerö in Norway; Horrsjöberg, Sweden, with lazulite and cyanite; Saualpe, Carinthia; in the Ural Mts.; in the Tyrol, Austria; at St. Gothard and Binnental, Switzerland; at Yrieux, near Limoges in France; at Ohlapian in Transylvania, *nigrine* in pebbles; in large crystals in Perthshire, Scotland; in Donegal Co., Ireland.

In Me., at Warren. In Ver., at Waterbury; also in loose bowlders in middle and northern Vermont, acicular, some specimens of great beauty in transparent quartz. In Mass., at Barre, in gneiss; at Shelburne, in mica slate, at Chester. In N. Y., in Orange Co., Edenville; Warwick; east of Amity. In Pa., at Sudsbury, Chester Co., and the adjoining district in Lancaster Co.; at Parksburg, Concord, West Bradford, and Newlin, Chester Co.; at the Poor House quarry, Chester Co. In N. J., at Newton, with spinel. In N. C., at Crowder's Mountain; at Stony Point, Alexander Co., in splendent crystals. In Ga., in Habersham Co.; in Lincoln Co., at Graves' Mountain, with lazulite in large and splendent crystals. In Ark., at Magnet Cove, commonly in twins, with brookite and perovskite, also as paramorphs after brookite.

Fine specimens of "rutilated quartz," from Minas Geraes, Brazil; Madagascar; Tavetch and elsewhere, Switzerland; West Hartford, Ver.; Alexander Co., N. C.

Use. — A source of titanium.

Plattnerite. Lead dioxide, PbO_2. Rarely in prismatic crystals, usually massive. H. = 5–5·5. G. = 8·5. Luster submetallic. Color iron-black. Streak chestnut-brown. From Leadhill and Wanlockhead, Scotland. Also at the "As You Like" mine, Mullan, Cœur d'Alêne Mts., Idaho.

Baddeleyite. Zirconium dioxide, ZrO_2. In tabular monoclinic crystals. H. = 6·5. G. = 5·5–6·0. Colorless to yellow, brown and black. Index, 1·74. From Ceylon; from Brazil near Caldas, Minas Geraes and Jacupiranga, (*brazilite*) where it is associated with *zirkelite*, $(Ca,Fe)O{\cdot}2(Zr,Ti,Th)O_2$. Noted at Mte. Somma, Vesuvius. Also near Bozeman, Mon. Various minerals occurring as rolled pebbles in the diamond sands of Brazil are known as *favas* (*beans*). Some of them consist of nearly pure TiO_2 others of nearly pure ZrO_2, while others are various phosphates. *Paredrite* is a "fava," composed of TiO_2 with a little water.

Uhligite. $Ca(Ti,Zr)O_5.Al(Ti,Al)O_5$. Isometric. Octahedral. Color black. Brown and transparent on thin edges. Found in a nepheline syenite on the shore of Lake Magad, East Africa.

OCTAHEDRITE. Anatase.

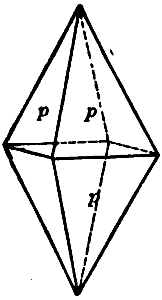
Tetragonal. Axis c = 1·7771.

Commonly octahedral in habit, either acute (p, 111), or obtuse (v, 117);

also tabular, *c*(001) predominating; rarely prismatic crystals; frequently highly modified.

ee', 101 ∧ 011 = 76° 5′.
ee'', 101 ∧ $\bar{1}$01 = 121° 16′.
pp', 111 ∧ $\bar{1}$11 = 82° 9′.
pp'', 111 ∧ $\bar{1}\bar{1}$1 = 136° 36′.
zz', 113 ∧ $\bar{1}$13 = 54° 1′.
vv', 117 ∧ $\bar{1}$17 = 27° 39′.

722



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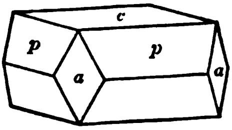

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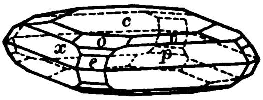


Cleavage: *c* (001) and *p* (111) perfect. Fracture subconchoidal. Brittle. H. = 5·5–6. G. = 3·82–3·95; sometimes 4·11–4·16 after heating. Luster adamantine or metallic-adamantine. Color various shades of brown, passing into indigo-blue, and black; greenish yellow by transmitted light. Streak uncolored. Transparent to nearly opaque. Optically –. Birefringence rather high. Indices: $\omega = 2{\cdot}554$, $\epsilon = 2{\cdot}493$. Sometimes abnormally biaxial.

Comp. — Titanium dioxide, TiO_2 = Oxygen 40·0, titanium 60·0 = 100.

Pyr., etc. — Same as for rutile.

Artif. — See under rutile.

Obs. — Most abundant at Bourg d'Oisans, in Dauphiné, France, with feldspar, axinite, and ilmenite; near Hof in the Fichtelgebirge, Germany; at Selva and Naderanertal, Switzerland; Norway; the Ural Mts.; in chlorite in Devonshire, near Tavistock; with brookite at Tremadoc, in North Wales; in Cornwall, near Liskeard and at Tintagel Cliffs; in Brazil in quartz, and in detached crystals. In Switzerland in the Binnental the variety *wiserine*, long supposed to be xenotime; also Cavradi, Tavetsch; Rauris, Salzburg, in the Eastern Alps; also at Pfitsch Joch.

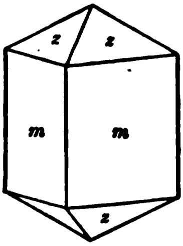
In the United States, at the Dexter lime rock, Smithfield, R. I., in dolomite; from granite pegmatite, Quincy, and from Somerville, Mass.; in the washings at Brindletown, Burke Co., N. C., in transparent tabular crystals; at Magnet Cove, Ark.; in unusual crystals from Beaver Creek, Gunnison Co., Col.

BROOKITE.

Orthorhombic. Axes *a* : *b* : *c* = 0·8416 : 1 : 0·9444.

mm''', 110 ∧ 1$\bar{1}$0 = 80° 10′.
zz', 112 ∧ $\bar{1}$12 = 53° 48′.
zz''', 112 ∧ 1$\bar{1}$2 = 44° 46′.
ee', 122 ∧ $\bar{1}$22 = 44° 23′.
ee''', 122 ∧ 1$\bar{2}$2 = 78° 57′.
me, 110 ∧ 122 = 45° 42′.

725



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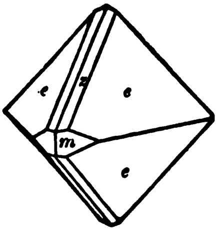

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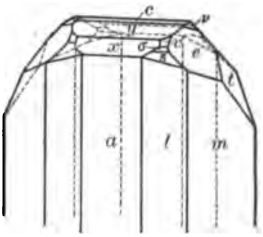


Only in crystals, of varied habit.

Cleavage: *m*(110) indistinct; *c*(001) still more so. Fracture subconchoidal to uneven. Brittle. H. = 5·5–6. G. = 3·87–4·08. Luster metallic-adamantine to submetallic. Color hair-brown, yellowish, reddish, reddish brown, and translucent; also brown to iron-black, opaque. Streak uncolored to grayish or yellowish. $\alpha = 2{\cdot}583$. $\beta = 2{\cdot}586$. $\gamma = 2{\cdot}741$. Other optical characters, see p. 298.

Comp. — Titanium dioxide, TiO_2 = Oxygen 40·0, titanium 60·0 = 100.

Pyr. — Same as for rutile.

Artif. — See under rutile.

Obs. — Occurs at Bourg d'Oisans in Dauphiné, France; in Switzerland at St. Gothard, with albite and quartz, and Maderanertal; in the Ural Mts.; district of Zlatoust, near Miask, and in the gold-washings in the Sanarka river and elsewhere; at Fronolen, near Tremadoc, Wales. From Companhia, Lençoes, Bahia, Brazil.

In the United States in thick black crystals (*arkansite*) at Magnet Cove, Ozark Mts., Ark., with elæolite, black garnet, schorlomite, rutile, etc.; in small crystals from the gold-washings of N. C.; at the lead mine at Ellenville, Ulster Co., N. Y., on quartz, with chalcopyrite and galena; at Paris, Me., Somerville, Mass.

Named after the English mineralogist, H. J. Brooke (1771–1857).

PYROLUSITE.

Orthorhombic, but perhaps only pseudomorphous. Commonly columnar, often divergent; also granular massive, and frequently in reniform coats.

Soft, often soiling the fingers. H. = 2–2·5. G. = 4·73–4·86. Luster metallic. Color iron-black, dark steel-gray, sometimes bluish. Streak black or bluish black, sometimes submetallic. Opaque.

Comp. — Manganese dioxide, MnO_2, like polianite (p. 427). Commonly contains a little water (2 p. c.), it having had usually a pseudomorphous origin (after manganite).

It is uncertain whether pyrolusite is an independent species, with a crystalline form of its own, or only a secondary mineral derived chiefly from the dehydration of manganite; also from polianite (Breith.). Pseudomorphous crystals having distinctly the form of manganite are common.

Pyr., etc. — Like polianite, but most varieties yield some water in the closed tube.

Diff. — Hardness less than that of psilomelane. Differs from iron ores in its reaction for manganese B.B. Easily distinguished from psilomelane by its inferior hardness, and usually by being crystalline. Its streak is black; that of manganite is more or less brown.

Obs. — Manganese ore deposits in general are secondary in origin, the manganese content of the rocks having been concentrated in favorable places. They often occur as irregular bodies in residual clays. Pyrolusite is extensively worked at Elgersberg near Ilmenau, and other places in Thuringia, Germany; at Vorderehrensdorf in Moravia; at Platten in Bohemia, and elsewhere; near Johanngeorgenstadt, at Hirschberg in Westphalia, Germany; Matzka, Transylvania; in Australia; in India.

Occurs in the United States with psilomelane, abundantly in Ver., at Brandon, etc.; at Plainfield and West Stockbridge, Mass.; Augusta Co., Va.; Pope, Pulaski, Montgomery Cos., Ark. Negaunee, Mich.; Lake Co., N. M. In New Brunswick, 7 m. from Bathurst. In Nova Scotia, at Teny Cape; at Walton, etc.

The name is from πῦρ, *fire*, and λούειν, *to wash*, because used to discharge the brown and green (FeO) tints of glass; and for the same reason it is whimsically entitled by the French *le savon de verriers*.

Use. — An ore of manganese; as an oxidizing agent in manufacture of chlorine, bromine and oxygen; as a drier in paints, a decolorizer in glass and in electric batteries, as coloring material in bricks, pottery, glass, etc.

B. HYDROUS OXIDES.

Among the hydrous oxides the DIASPORE GROUP is well characterized. Here belong the hydroxides of aluminium, iron and manganese. The general formula is properly written $\overset{\text{III}}{R}O(OH)$. The three species here included are orthorhombic in crystallization with related angles and axial ratios; this relation is deviated from by manganite in the prismatic zone.

Another less prominent group is the BRUCITE GROUP, including the rhombohedral species Brucite, Mg(OH), and Pyrochroite, Mn(OH).

Gibbsite, $Al(OH)_3$, and Sassolite, $B(OH)_3$, are also related, and further Hydrotalcite and Pyroaurite.

Diaspore Group. $\overset{\text{III}}{R}O(OH)$ or $R_2O_3.H_2O$. Orthorhombic.

		$a : b : c$	$\frac{c}{a}$
Diaspore	$Al_2O_3.H_2O$	0·9372 : 1 : 0·6039 or	0·6443
Göthite	$Fe_2O_3.H_2O$	0·9185 : 1 : 0·6068 or	0·6606
Manganite	$Mn_2O_3.H_2O$	0·8441 : 1 : 0·5448 or	0·6463

DIASPORE.

Orthorhombic. Axes: $a : b : c$ = 0·9372 : 1 : 0·6039. Crystals prismatic, *mm'''*, 110 ∧ 1$\bar{1}$0, = 86° 17'; usually thin, flattened ‖ *b*(010); sometimes acicular. Also foliated massive and in thin scales; sometimes stalactitic.

Cleavage: *b*(010) eminent; *h*(210) less perfect. Fracture conchoidal, very brittle. H. = 6·5–7. G. = 3·3–3·5. Luster brilliant; pearly on cleavage-face, elsewhere vitreous. Color whitish, grayish white, greenish gray, hair-brown, yellowish, to colorless. Pleochroic. Transparent to subtranslucent. Optically +. Birefringence high. Ax. pl. ‖ *b*(010). Bx. ⊥ *a*(100). Dispersion $\rho < v$, feeble. 2 V = 84°. α = 1·702. β = 1·722. γ = 1·750.

Comp. — AlO(OH) or $Al_2O_3.H_2O$ = Alumina 85·0, water 15·0 = 100.

Pyr., etc. — In the closed tube usually decrepitates strongly, separating into white pearly scales, and at a high temperature yields water. Infusible; ignited with cobalt solution gives a deep blue color. Not attacked by acids, but after ignition soluble in sulphuric acid.

Diff. — Distinguished by its hardness and pearly luster; also (B.B.) by its decrepitation and yielding water; by the reaction for alumina with cobalt solution. Resembles some varieties of hornblende, but is harder.

Artif. — Diaspore crystals have been artificially formed by heating in a steel tube aluminium oxide in sodium hydroxide to temperatures less than 500°.

Obs. — Commonly found with corundum or emery. Occurs near Kossoibrod, in the Ural Mts.; at Schemnitz, Hungary; with corundum in dolomite at Campolongo, Tessin, in Switzerland; Greiner in the Zillertal, Austria. In the United States, with corundum and margarite at Newlin, Chester Co., Pa.; at the emery mines of Chester, Mass.; in cavities in massive corundum at the Culsagee mine, near Franklin, Macon Co., N. C.; with alunite forming rock masses at Mt. Robinson, Rosita Hills, Col.

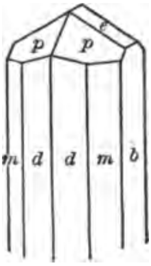
Named by Haüy from *διασπείρειν*, *to scatter*, alluding to the usual decrepitation before the blowpipe.

GÖTHITE.

Orthorhombic. Axes $a : b : c$ = 0·9185 : 1 : 0·6068.

mm''', 110 ∧ 1$\bar{1}$0 = 85° 8'. *pp'*, 111 ∧ $\bar{1}$11 = 58° 55'.
ee', 011 ∧ 0$\bar{1}$1 = 62° 30'. *pp''*, 111 ∧ 1$\bar{1}$1 = 53° 42'.

728



In prisms vertically striated, and often flattened into scales or tables ‖ *b*(010). Also fibrous; foliated or in scales; massive, reniform and stalactitic, with concentric and radiated structure.

Cleavage: *b*(010) very perfect. Fracture uneven. Brittle. H. = 5–5·5. G. = 4·28. Luster imperfect adamantine. Color yellowish, reddish, and blackish brown. Often blood-red by transmitted light. Streak brownish yellow to ocher-yellow. α = 2·26. β = 2·39. γ = 2·4. Only weakly pleochroic.

Var. — In thin scale-like or tabular crystals, usually attached by one edge. Also in acicular or capillary (not flexible) crystals, or slender prisms, often radiately grouped: the *Needle-Ironstone.* It passes into a variety with a velvety surface; the *Przibramite* (*Sammetblende*) of Přibram, Bohemia, is of this kind. Also columnar, fibrous, etc., as above.

Comp. — FeO(OH) or $Fe_2O_3.H_2O$ = Oxygen 27·0, iron 62·9, water 10·1 = 100, or Iron sesquioxide 89·9, water 10·1 = 100.

Pyr., etc. — In the closed tube gives off water and is converted into red iron sesquioxide. With the fluxes like hematite; most varieties give a manganese reaction, and some, treated in the forceps in O.F., after moistening in sulphuric acid, impart a bluish green color to the flame (phosphoric acid). Soluble in hydrochloric acid.

Diff. — Distinguished from hematite by its yellow streak; from limonite by crystalline nature; it also contains less water than limonite.

Obs. — Found with the other oxides of iron, especially hematite or limonite. Occurs at Eiserfeld near Siegen, in Nassau, Germany; Přibram, Bohemia; at Clifton, near Bristol, England; in Cornwall. In the United States, at the Jackson Iron mine, Negaunee, Lake Superior; in Conn., at Salisbury; in Pa., near Easton; in the Pike's Peak region and at Crystal Peak, Col. Named *Göthite* (Goethite) after the poet-philosopher Goethe (1749–1832).

A colloidal form of iron hydroxide having the composition of *goethite* and occurring as pseudomorphs after pyrite has been called *ehrenwerthite.*

Use. — An ore of iron.

Lepidocrocite. A dimorphous form of goethite. Orthorhombic but with different axial ratio. Scaly, fibrous. G = 4·09. β = 2·20. Strongly pleochroic.

MANGANITE.

Orthorhombic. Axes $a : b : c$ = 0·8441 : 1 : 0·5448.

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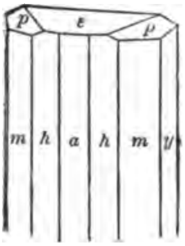
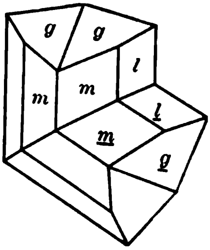


730



hh''', $410 \wedge 4\bar{1}0 = 23° 50'$.
mm''', $110 \wedge 1\bar{1}0 = 80° 20'$.
$\epsilon\epsilon'$, $205 \wedge \bar{2}05 = 28° 57'$.
ee', $011 \wedge 0\bar{1}1 = 57° 10'$.
pp', $111 \wedge \bar{1}11 = 59° 5\frac{1}{2}'$.

Crystals commonly prismatic, the faces deeply striated vertically; often grouped in bundles. Twins: tw. pl. e(011). Also columnar; stalactitic.

Cleavage: b(010) very perfect; m(110) perfect. Fracture uneven. Brittle. H. = 4. G. = 4·2–4·4. Luster submetallic. Color dark steel-gray to iron-black. Streak reddish brown, sometimes nearly black. Opaque; in minute splinters sometimes brown by transmitted light.

Comp. — MnO(OH) or $Mn_2O_3.H_2O$ = Oxygen 27·3, manganese 62·4, water 10·3 = 100, or Manganese sesquioxide 89·7, water 10·3 = 100.

Pyr., etc. — In the closed tube yields water; manganese reactions with the fluxes, p. 339.

Obs. — Occurs in Germany at Ilefeld in the Harz Mts.; Ilmenau in Thuringia; Långban and Bölet, Sweden; Cornwall, at various places; also in Cumberland, etc. In the Lake Superior mining region at the Jackson mine, Negaunee; Devil's Head, Douglas Co., Col. In Nova Scotia, at Cheverie, Hants Co., and Walton. In New Brunswick, at Shepody mountain, Albert Co., etc.

Sphenomanganite is a variety of manganite from Långban, Sweden, showing sphenoidal forms.

Use. — An ore of manganese.

LIMONITE. Brown Hematite.

Not crystallized. Usually in stalactitic and botryoidal or mammillary forms, having a fibrous or subfibrous structure; also concretionary, massive; and occasionally earthy.

H. = 5–5·5. G. = 3·6–4·0. Luster silky, often submetallic; sometimes dull and earthy. Color of surface of fracture various shades of brown, commonly dark, and none bright; sometimes with a nearly black varnish-like exterior; when earthy, brownish yellow, ocher-yellow. Streak yellowish brown. Opaque.

Var. — (1) *Compact.* Submetallic to silky in luster; often stalactitic, botryoidal, etc. (2) *Ocherous* or earthy, brownish yellow to ocher-yellow, often impure from the presence of clay, sand, etc. (3) *Bog ore.* The ore from marshy places, generally loose or porous in texture, often petrifying leaves, wood, nuts, etc. (4) *Brown clay-ironstone*, in compact masses, often in concretionary nodules.

Comp. — Approximately $2Fe_2O_3.3H_2O$ = Oxygen 25·7, iron 59·8, water 14·5 = 100, or Iron sesquioxide 85·5, water 14·5 = 100. The water content varies widely and it is probable that limonite is essentially an amorphous form of goethite with adsorbed and capillary water. In the bog ores and ochers, sand, clay, phosphates, oxides of manganese, and humic or other acids of organic origin are very common impurities.

Pyr., etc. — Like göthite. Some varieties leave a siliceous skeleton in the salt of phosphorus bead, and a siliceous residue when dissolved in acids.

Diff. — Distinguished from hematite by its yellowish streak, inferior hardness, and its reaction for water. Does not decrepitate B.B., like turgite. Not crystallized like göthite and yields more water.

Obs. — In all cases a result of the alteration of other ores, or minerals containing iron, through exposure to moisture, air, and carbonic or organic acids; derived largely from the change of pyrite, magnetite, siderite, ferriferous dolomite, etc.; also various species (as mica, pyroxene, hornblende, etc.), which contain iron in the ferrous state (FeO). Waters containing iron in solution when brought into marshy places deposit the metal usually in the form of limonite. The evaporation of the carbonic acid in the water which held the iron in solution is one cause for the separation of the iron oxide. This separation is also aided by the so-called "iron bacteria" which absorb the iron from the water and later deposit it again as ferric hydroxide. Limonite consequently occupies, as a bog ore, marshy places, into which it has been borne by streamlets from the hills around. It is also found in deposits associated with iron-bearing limestones where the original iron content of the rock has been largely dissolved and redeposited later in some favorable spot. Limonite forms the capping or *gossan, iron hat,* of many metallic veins. It is often associated with manganese ores. Limonite is a common ore in Bavaria, the Harz Mts., Germany, Luxemburg, Scotland, Sweden, etc.

Abundant in the United States. Extensive beds exist at Salisbury and Kent, Conn., also in the neighboring towns of N. Y., and in a similar situation in Berkshire Co., Mass., and in Ver.; in Pa., widely distributed; also in Tenn., Ala., Ohio, etc.

Named *Limonite* from *λειμών, meadow.*

Use. — An ore of iron; as a yellow pigment.

TURGITE. Hydrohematite. Approximately $2Fe_2O_3.H_2O$. Probably to be considered as a solid solution of goethite with hematite together with enclosed and adsorbed water. Resembles limonite but has a red streak. G. = 4·14–4·6. Decrepitates B.B. From the Turginsk mine in the Ural Mts., etc.; also from Salisbury, Conn. Intermediate between hematite and limonite.

HYDROGOETHITE. $3Fe_2O_3.4H_2O$. Orthorhombic, radiating fibrous. H. = 4. G. = 3·7. Color and streak brick-red. With limonite at various localities in Tula, Russia.

Xanthosiderite. $Fe_2O_3.2H_2O$. In fine needles or fibers, stellate and concentric; also as an ocher. Color golden yellowish, brown to brownish red. Associated with manganese ores at Ilmenau, Thuringia, Germany, etc.

Esmeraldaite. $Fe_2O_3.4H_2O$. In small pod-shaped masses enclosed in limonite. Conchoidal fracture. H. = 2·5. G. = 2·58. Color coal black. Yellow-brown streak. From Esmeralda Co., ~~Cal.~~ Nev.

BAUXITE. Beauxite.

In round concretionary disseminated grains. Also massive, oölitic; and earthy, clay-like. G. = 2·55. Color whitish, grayish, to ocher-yellow, brown, and red.

Var. — 1. In concretionary grains, or oölitic; *bauxite*. 2 Clay-like, *wocheinite;* the purer kind grayish, clay-like, containing very little iron oxide; also red from the iron oxide present.

Comp. — Essentially $Al_2O_3.2H_2O$ = Alumina 73·9, water 26·1 = 100; some analyses, however, give $Al_2O_3.H_2O$ like diaspore.

Bauxite is probably a mixture of varying character but containing large amounts of a colloidal form of $Al_2O_3.H_2O$. This substance has been called *sporogelite* or *diasporogelite, cliachite* and *alumogel*.

Iron sesquioxide is usually present, sometimes in large amount, in part replacing alumina, in part only an impurity. The name *hematogelite* has been suggested for this colloidal form of ferric oxide. Silica, phosphoric acid, carbonic acid, lime, magnesia are common impurities.

Obs. — Bauxite is a product of the decomposition of certain rocks, particularly those rich in plagioclase feldspars, and has been found under various conditions. The laterites of India, etc., are probably similar in origin and might be considered as iron-rich bauxites. Bauxite is certainly not a definite mineral species but consists of a mixture of several different materials. From Baux (or Beaux), near Arles, and elsewhere in France, disseminated in grains in compact limestone, and also oölitic. *Wocheinite* occurs in Carniola, Austria, between Feistritz and Lake Wochein. The purest bauxite is used for the manufacture of aluminium (aluminum), and is called *aluminum ore*. In the United States, bauxite occurs in Saline and Pulaski Cos., Ark.; also in Cherokee and Calhoun Cos., Ala., and in Floyd, Barton and Walker Cos., Ga.

Use. — As an aluminum ore.

Brucite Group. $R(OH)_2$. Rhombohedral

BRUCITE.

Rhombohedral. Axis $c = 1{\cdot}5208$; cr 0001 ∧ 1011 = 60° 20½′, rr' $10\bar{1}1$ ∧ $\bar{1}101$ = 97° 37½′.

Crystals usually broad tabular. Also commonly foliated massive; fibrous, fibers separable and elastic.

H. = 2·5. G. = 2·38–2·4. Cleavage: $c(0001)$ eminent. Folia separable and flexible, nearly as in gypsum. Sectile. Luster $\parallel c$ pearly, elsewhere waxy to vitreous. Color white, inclining to gray, blue, or green. Transparent to translucent. Optically +. Indices: $\omega_r = 1{\cdot}559$, $\epsilon_r = 1{\cdot}5795$.

Comp. — Magnesium hydroxide, $Mg(OH)_2$ or $MgO.H_2O$ = Magnesia 69·0, water 31·0 = 100. Iron and manganese protoxide are sometimes present.

Var. — *Ordinary*, occurring in plates, white to pale greenish in color; strong pearly luster on the cleavage surface. *Nemalite* is a fibrous variety containing 4 to 5 p. c. iron protoxide, with G. = 2·44. *Manganbrucite* contains manganese; occurs granular; color honey-yellow to brownish red. *Ferrobrucite* contains iron.

Pyr., etc. — In the closed tube gives off water, becoming opaque and friable, sometimes turning gray to brown; the manganesian variety becomes dark brown. B.B. infusible, glows with a bright light, and the ignited mineral reacts slightly alkaline to test-paper. Ignited with cobalt solution gives the pale pink color of magnesia. The pure mineral is soluble in acids without effervescence.

Diff. — Distinguished by its infusibility, softness, cleavage, and foliated structure. Is harder than talc and differs in its solubility in acids; the magnesia test and optical characters separate it from gypsum, which is also somewhat softer.

Obs. — A secondary mineral accompanying other magnesian minerals in serpentine, also found in limestone. At Swinaness in Unst, Shetland Isles; at the iron mine of Cogne, Aosta, Italy; near Filipstadt in Sweden. At Hoboken, N. J., in serpentine; at the Tilly Foster iron mine, Brewster, N. Y., well crystallized; Richmond Co., N. Y.; at Wood's mine, Texas Pa., in large plates or masses, and often crystallizations several inches across, also at Low's mine with hydromagnesite. From Crestmore, Riverside Co., Cal. *Nemalite*, the fibrous variety, occurs at Hoboken, N. J., and at Xettes in the Vosges Mts. *Mangan-*

brucite occurs with hausmannite and other manganese minerals in the granular limestone of Jakobsberg, Nordmark, Sweden.

Named after the early American mineralogist, A. Bruce (1777–1818).

Pyrochroite. — Manganese hydroxide, Mn(OH)$_2$. Usually foliated, like brucite. Luster pearly. Color white, but growing dark on exposure. $\omega = 1·723$. $\epsilon = 1·681$. In Sweden occurs in magnetite at Pajsberg, also at Nordmark and Långban; in N. J. at Franklin Furnace.

Bäckströmite. Manganese hydroxide, Mn(OH)$_2$. Orthorhombic. From Långban, Sweden.

GIBBSITE. Hydrargillite.

Monoclinic. Axes $a : b : c = 1·7089 : 1 : 1·9184$; $\beta = 85° 29'$. Crystals tabular || $c(001)$, hexagonal in aspect. Occasionally in spheroidal concretions. Also stalactitic, or small mammillary, incrusting, with smooth surface, and often a faint fibrous structure within.

Cleavage: $c(001)$ eminent. Tough. H. = 2·5–3·5. G. = 2·3–2·4. Color white, grayish, greenish, or reddish white. Luster of $c(001)$ pearly; of other faces vitreous; of surface of stalactites faint. Translucent; sometimes transparent in crystals. Indices, 1·535–1·558. A strong argillaceous odor when breathed on.

Comp. — Aluminium hydroxide, Al(OH)$_3$ or Al$_2$O$_3$.3H$_2$O = Alumina 65·4, water 34·6 = 100.

Pyr., etc. — In the closed tube becomes white and opaque, and yields water. B.B. infusible, whitens, and does not impart a green color to the flame. Ignited with cobalt solution gives a deep blue color. Soluble in concentrated sulphuric acid.

Artif. — When solutions of sodium aluminate are slowly decomposed by carbon dioxide gibbsite is precipitated.

Obs. — The crystallized gibbsite (hydrargillite) occurs in the Shishimsk mountains near Zlatoust in the Ural Mts.; also in crystals filling cavities in natrolite at Langesundfiord, Norway; Ouro Preto, Minas Geraes, Brazil. Occurs in nodular plates at Kodikanal, Palni Hills, Madras, and at Talevadi, Bombay, India. In the United States, in stalactitic form at Richmond, Mass., in a bed of limonite; at the Clove Mine, Union Vale, Dutchess Co., N. Y., on limonite; in Orange Co., N. Y.

Named after Col. George Gibbs.

Sassolite. Boric acid, B(OH)$_3$. Crystals tabular || $c(001)$ (triclinic). Usually small, white, pearly scales. G. = 1·48. Index, 1·46. From the waters of the Tuscan lagoons of Monte Rotondo and Castelnuovo, Italy. Exists also in other natural waters, as at Clear Lake, in Lake Co., Cal. Occurs also abundantly in the crater of Vulcano, Lipari isles.

Hydrotalcite. Perhaps Al(OH)$_3$.3Mg(OH)$_2$.3H$_2$O. Lamellar-massive, or foliated, somewhat fibrous. H. = 2. G. = 2·04–2·09. Color white. Luster pearly. Uniaxial, −. $\omega = 1·47$. Occurs at the mines of Shishimsk, district of Zlatoust, Ural Mts.; at Snarum, Norway, in serpentine.

Pyroaurite. Perhaps Fe(OH)$_3$.3Mg(OH)$_2$.3H$_2$O. Rhombohedral. Thin tabular crystals. H. = 2–3. G. = 2·07. Luster pearly to greasy. Color yellow to yellow-brown. Optically −. Occurs at the Långban iron-mine, Wermland, Sweden, in gold-like submetallic scales (*pyroaurite*). From the Moss mine, Norway. In thin seams of a silvery white color in serpentine in the island Haaf-Grunay, Scotland (*igelströmite*).

Chalcophanite. Hydrofranklinite. (Mn,Zn)O.2MnO$_2$.2H$_2$O. In druses of minute tabular rhombohedral crystals; sometimes octahedral in aspect. Also in foliated aggregates; stalactitic and plumose. G. = 3·907. Luster metallic, brilliant. Color bluish black to iron-black. Streak chocolate-brown, dull. Occurs at Sterling Hill, near Ogdensburg, Sussex Co., N. J. From Leadville, Col.

Hetaerolite. 2ZnO.2Mn$_2$O$_3$.1H$_2$O. In radiating botryoidal masses. Black. Brown-black streak. H. = 5. G. = 4·85. From Franklin, N. J., and Leadville, Col. (*Wolftonite*).

Alaïte. $V_2O_5.H_2O$. Rare. Found in dark bluish red moss-like masses in Alai Mts., Turkestan.

Shanyavskite. $Al_2O_3.4H_2O$. Amorphous, transparent material found in dolomite, near Moscow, Russia.

PSILOMELANE.

Massive and botryoidal; reniform; stalactitic. H. = 5–6. G. = 3·7–4·7. Luster submetallic, dull. Streak brownish black, shining. Color iron-black, passing into dark steel-gray. Opaque.

Comp. — A hydrous manganese manganate in which part of the manganese is often replaced by barium or potassium, perhaps conforming to H_4MnO_5. The material is generally very impure, and the composition hence doubtful.

Pyr., etc. — In the closed tube most varieties yield water, and all lose oxygen on ignition; with the fluxes reacts for manganese. Soluble in hydrochloric acid, with evolution of chlorine.

Obs. — A common but impure ore of manganese; frequently in alternating layers with pyrolusite. From Devonshire and Cornwall. In Germany at Ilefeld in the Harz Mts., at Ilmenau, Siegen, etc. From the Crimea, Russia; also various localities in India. Forms mammillary masses at Brandon, etc., Vt. In Independence Co., and elsewhere in Ark. With pyrolusite at Douglas, Hants Co., Nova Scotia. Named from ψιλός, *smooth* or *naked*, and μέλας, *black*.

Use. — An ore of manganese.

The following mineral substances here included are mixtures of various oxides, chiefly of manganese (MnO_2, also MnO), cobalt, copper, with also iron, and from 10 to 20 p. c. water. These are results of the decomposition of other ores — partly of oxides and sulphides, partly of manganesian carbonates, and can hardly be regarded as representing distinct mineral species.

Wad. In amorphous and reniform masses, either earthy or compact; also incrusting or as stains. Usually very soft, soiling the fingers; less often hard to H. = 6. G. = 3·0–4·26; often loosely aggregated, and feeling very light to the hand. Color dull black, bluish or brownish black.

Bog Manganese consists mainly of oxide of manganese and water, with some oxide of iron, and often silica, alumina, baryta.

Asbolite, or *Earthy Cobalt*, contains oxide of cobalt, which sometimes amounts to 32 p. c.

Lampadite, or *Cupreous Manganese*, is a wad containing 4 to 18 p. c. of oxide of copper, and often oxide of cobalt also.

Skemmatite. $3MnO_2.2Fe_2O_3.6H_2O$. Color black. Streak dark brown. H. = 5·5–6. Fusible to magnetic globule. Alteration product of *pyroxmangite.* From Iva, Anderson Co., S. C.

Beldongrite. $6Mn_3O_5.Fe_2O_3.8H_2O$. Luster pitchy. Color black. From Beldongri, District Nágpur, India.

VI. OXYGEN-SALTS

The Sixth Class includes the salts of the various oxygen acids. These fall into the following seven sections: 1. Carbonates; 2. Silicates and Titanates; 3. Niobates and Tantalates; 4. Phosphates, Arsenates, etc.; also the Nitrates; 5. Borates and Uranates; 6. Sulphates, Chromates and Tellurates; 7. Tungstates and Molybdates.

1. CARBONATES

A. Anhydrous Carbonates

The Anhydrous Carbonates include two distinct isomorphous groups, the Calcite Group and the Aragonite Group. The metallic elements present in the former are calcium, magnesium, iron, manganese, zinc and cobalt; in the latter, they are calcium, barium, strontium and lead.

The species included are as follows:

1. *Calcite Group.* RCO_3. Rhombohedral

			rr'	c
Calcite	$CaCO_3$		74° 55′	0·8543
Dolomite	$(Ca,Mg)CO_3$	Tri-rhombohedral	73° 45′	0·8322
Normal Dolomite	$CaCO_3.MgCO_3$			
Ankerite	$CaCO_3.(Mg,Fe)CO_3$		73° 48′	0·8332
Magnesite	$MgCO_3$		72° 36′	0·8112
Breunnerite	$(Mg,Fe)CO_3$			
Mesitite	$2MgCO_3.FeCO_3$		72° 46′	0·8141
Pistomesite	$MgCO_3.FeCO_3$		72° 42′	0·8129
Siderite	$FeCO_3$		73° 0′	0·8184
Oligonite	$(Fe,Mn)CO_3$			
Rhodochrosite	$MnCO_3$		73° 0′	0·8184
Manganosiderite	$(Mn,Fe)CO_3$			
Manganocalcite pt.	$(Mn,Ca)CO_3$			
Smithsonite	$ZnCO_3$		72° 20′	0·8063
Monheimite	$(Zn,Fe)CO_3$			
Sphærocobaltite	$CoCO_3$			

This list gives not only the prominent species of this group, but also some of the isomorphous intermediate compounds.

The CALCITE GROUP is characterized by rhombohedral crystallization. All the species show, when distinctly crystallized, perfect rhombohedral cleavage, the angle varying from 75° (and 105°) in calcite to 73° (and 107°) in siderite. This is exhibited in the table above.

2. *Aragonite Group.* RCO_3. Orthorhombic

		mm'''	$a : b : c$
Aragonite	$CaCO_3$	63° 48′	0·6224 : 1 : 0·7206
Bromlite	$(Ca,Ba)CO_3$		
Witherite	$BaCO_3$	62° 12′	0·6032 : 1 : 0·7302
Strontianite	$SrCO_3$	62° 41′	0·6090 : 1 : 0·7239
Cerussite	$PbCO_3$	62° 46′	0·6100 : 1 : 0·7230

The species of the ARAGONITE GROUP crystallize in the orthorhombic system, but the relation to those of the Calcite Group is made more close by the fact that the prismatic angle varies a few degrees only from 60° (and 120°) and the twinned forms with the fundamental prism as twinning-plane are pseudo-hexagonal in character.

1. *Calcite Group.* RCO_3. Rhombohedral

CALCITE. Calc Spar; Calcareous Spar.

Rhombohedral. Axis $c = 0{\cdot}8543$.

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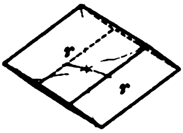

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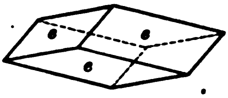

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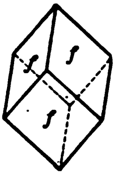

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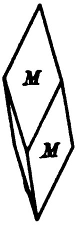

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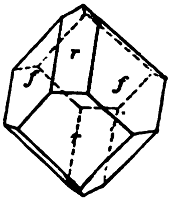

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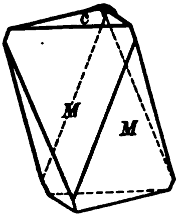

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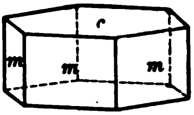

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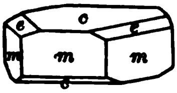

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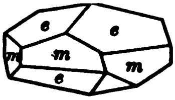

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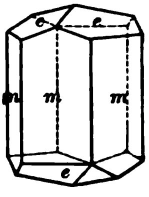

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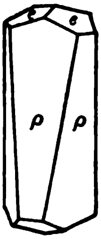

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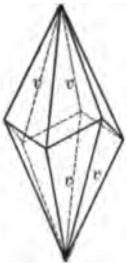

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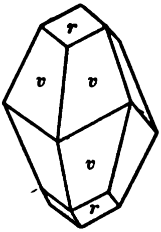

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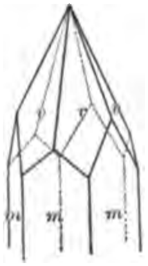

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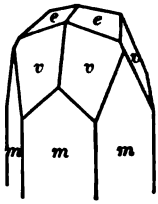

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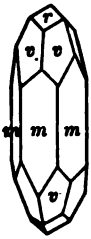

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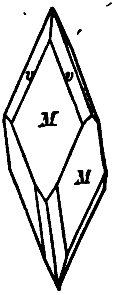

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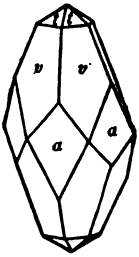

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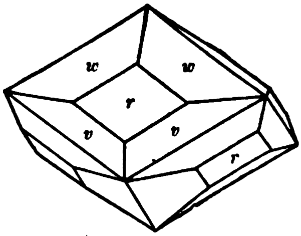

cr,* $0001 \wedge 10\bar{1}1 = 44°\ 36\tfrac{1}{2}'$.
ce, $0001 \wedge 01\bar{1}2 = 26°\ 15'$.
me, $10\bar{1}0 \wedge 01\bar{1}2 = 63°\ 45'$.
rr′, $10\bar{1}1 \wedge \bar{1}101 = 74°\ 55'$.
MM′, $40\bar{4}1 \wedge \bar{4}401 = 114°\ 10'$.
ee′ $01\bar{1}2 \wedge \bar{1}012 = 45°\ 3'$.
φφ′, $05\bar{5}4 \wedge \bar{5}054 = 84°\ 32\tfrac{1}{2}'$.
ff′, $02\bar{2}1 \wedge \bar{2}021 = 101°\ 9'$.

vv′, $21\bar{3}1 \wedge \bar{2}3\bar{1}1 = 75°\ 22'$.
vv^{v}, $21\bar{3}1 \wedge 3\bar{1}\bar{2}1 = 35°\ 36'$.
vv^{vi}, $21\bar{3}1 \wedge 12\bar{3}\bar{1} = 47°\ 1\tfrac{1}{2}'$.
yy′, $32\bar{5}1 \wedge \bar{3}5\bar{2}1 = 70°\ 59'$.
yy^{v}, $32\bar{5}1 \wedge 5\bar{2}\bar{3}1 = 45°\ 32'$.
yy^{vi}, $32\bar{5}1 \wedge 23\bar{5}\bar{1} = 29°\ 16'$.
tt^{v}, $21\bar{3}4 \wedge 3\bar{1}\bar{2}4 = 20°\ 36\tfrac{1}{2}'$.
ww^{v}, $31\bar{4}5 \wedge 4\bar{1}\bar{3}5 = 16°\ 0'$.

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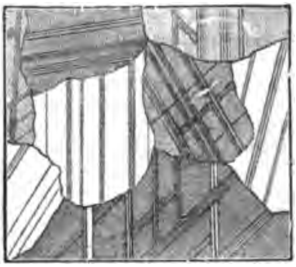
* See the stereographic projection, Fig. 269, p. 108.

Habit of crystals very varied, as shown in the figures, from obtuse to acute rhombohedral; from thin tabular to long prismatic; and scalenohedral of many types, often highly modified.

Twins (see Figs. 419–426, p. 168): (1) Tw. pl. $c(0001)$, common, the crystals having the same vertical axis. (2) Tw. pl. $e(01\bar{1}2)$, very common, the vertical axes inclined 127° $29\frac{1}{2}'$ and 52° $30\frac{1}{2}'$; often producing twinning lamellæ as in Iceland Spar, which are, in many cases, of secondary origin as in granular limestones (Fig. 750); this twinning may be produced artificially (see p. 188). (3) Tw. pl. $r(10\bar{1}1)$, not common; the vertical axes inclined 90° 46′ and 89° 14′. (4) Tw. pl. $f(02\bar{2}1)$, rare; the axes intersect at angles of 53° 46′ and 126° 14′.

750



Section of crystalline limestone in polarized light.

Also fibrous, both coarse and fine; sometimes lamellar; often granular; from coarse to impalpable, and compact to earthy. Also stalactitic, tuberose, nodular, and other imitative forms.

Cleavage: $r(10\bar{1}1)$ highly perfect. Parting || $e(01\bar{1}2)$ due to twinning. Fracture conchoidal, obtained with difficulty. H. = 3, but varying with the direction on the cleavage face; earthy kinds softer. G. = 2·714, in pure crystals, but varying somewhat widely in impure forms, as in those containing iron, manganese, etc. Luster vitreous to subvitreous to earthy. Color white or colorless; also various pale shades of gray, red, green, blue, violet, yellow; also brown and black when impure. Streak white or grayish. Transparent to opaque.

Optically −. Birefringence very high. Refractive indices for the D line: $\omega = 1·65849$, $\epsilon = 1·48625$.

Comp. — Calcium carbonate, $CaCO_3$ = Carbon dioxide 44·0, lime 56·0 = 100. Small quantities of magnesium. iron, manganese, zinc, and lead may be present replacing the calcium.

Var. — The varieties are very numerous, and diverse in appearance. They depend mainly on the following points: differences in crystallization and structural condition, presence of impurities, etc., the extremes being perfect crystals and earthy massive forms; also on composition as affected by isomorphous replacement.

A. VARIETIES BASED CHIEFLY UPON CRYSTALLIZATION AND ACCIDENTAL IMPURITIES

1. *Ordinary.* In crystals and cleavable masses, the crystals varying very widely in habit as already noted. *Dog-tooth Spar* is an acute scalenohedral form; *Nail-head Spar,* a composite variety having the form suggested by the name. The transparent variety from Iceland, used for polarizing prisms, etc., is called *Iceland Spar* or *Doubly-refracting Spar.* As regards *color,* crystallized calcite varies from the kinds which are perfectly clear and colorless through yellow, pink, purple, blue, to brown and black. The color is usually pale except as caused by impurities. These impurities may be pyrite, native copper, malachite, sand, etc.; they are sometimes arranged in symmetrical form, as depending upon the growth of the crystals and hence produce many varieties.

Fontainebleau limestone, from Fontainebleau and Nemours, France, contains a large amount of sand, some 50 to 63 p. c. Siliceous calcite crystals come from S. D., Wy., Cal., etc.

2. *Fibrous and lamellar kinds. Satin Spar* is fine fibrous, with a silky luster; resembles fibrous gypsum, also called satin spar, but is much harder than gypsum and effervesces with acids. *Lublinite* is a fibrous variety, probably pseudomorphous after some organic material.

Argentine is a pearly lamellar calcite, the lamellæ more or less undulating; color white, grayish, yellowish. *Aphrite*, in its harder and more sparry variety, is a foliated white pearly calcite, near argentine; in its softer kinds it approaches chalk, though lighter, pearly in luster, silvery white or yellowish in color, soft and greasy to the touch, and more or less scaly in structure. Aphrite has been thought to be aragonite pseudomorphous after gypsum.

3. *Granular massive to cryptocrystalline kinds: Limestone, Marble, Chalk.*

Granular limestone or *Saccharoidal limestone*, so named because like loaf sugar in fracture, varying from coarse to very fine granular, and hence to *compact* limestone; colors are various, as white, yellow, reddish, green; usually they are clouded and give a handsome effect when the material is polished. When such limestones are fit for polishing, or for architectural or ornamental use, they are called *marbles*. Many varieties have special names. *Shell-marble* consists largely of fossil shells; *Lumachelle* or *fire-marble* is a dark brown shell-marble, with brilliant fire-like or chatoyant internal reflections. *Ruin-marble* is a kind of a yellow to brown color, showing, when polished, figures bearing some resemblance to fortifications, temples, etc., in ruins, due to infiltration of iron oxide, etc.

Lithographic stone is a very even-grained compact limestone, of buff or drab color; as that of Solenhofen, Bavaria. *Hydraulic limestone* is an impure limestone which after ignition sets, i.e., takes a solid form under water, due to the formation of a silicate. The French varieties contain 2 or 3 p. c. of magnesia, and 10 to 20 of silica and alumina (or clay). The varieties in the United States contain 20 to 40 p. c. of magnesia, and 12 to 30 p. c. of silica and alumina. *Hard compact limestone* varies from nearly pure white, through grayish, drab, buff, yellowish, and reddish shades, to bluish gray, dark brownish gray, and black, and sometimes variously veined. Many kinds make beautiful marble when polished. Red oxide of iron produces red of different shades. Shades of green are due to iron protoxide, chromium oxide, iron silicate.

Chalk is white, grayish white, or yellowish, and soft enough to leave a trace on a board. It is composed of the shells of minute sea organisms. *Calcareous marl* is a soft earthy deposit, with or without distinct fragments of shells; it generally contains much clay, and graduates into a calcareous clay.

Oölite is a granular limestone, its grains minute concretions, looking somewhat like the roe of fish, the name coming from *ώόν, egg*. *Pisolite* consists of concretions as large often as a small pea, or larger, having usually a distinct concentric structure.

Deposited from calcareous springs, streams, or in caverns, etc. (*a*) *Stalactites* are calcareous cylinders or cones that hang from the roofs of limestone caverns, and which are formed from the waters that drip through the roof; these waters hold some calcium bicarbonate in solution, and leave calcium carbonate to form the stalactite when evaporation takes place. Stalactites vary from transparent to nearly opaque; from a crystalline structure with single cleavage directions to coarse or fine granular cleavable and to radiating fibrous; from a white color and colorless to yellowish gray and brown. (*b*) *Stalagmite* is the same material covering the floors of caverns, it being made from the waters that drop from the roofs, or from sources over the bottom or sides; cones of it sometimes rise from the floor to meet the stalactites above. It consists of layers, irregularly curved, or bent. Stalagmite, or a solid kind of travertine (see below) when on a large scale, is the alabaster stone of ancient writers, that is, the stone of which ointment vases, of a certain form called *alabasters*, were made. A locality near Thebes, now well known, was largely explored by the ancients, and the material has often been hence called *Egyptian alabaster*. It was also formerly called *onyx* and *onychites* because of its beautiful banded structure. In the arts it is often now called *Oriental alabaster* or *onyx marble*. Very beautiful marble of this kind is obtained in Algeria. *Mexican onyx* is a similar material obtained from Tecali, Puebla, Mexico; also in a beautiful brecciated form from the extinct crater of Zempoaltepec in southern Mexico. Similar kinds occur in Missouri, Arizona, San Luis Obispo Co., California. (*c*) *Calc-sinter*, *Travertine*, *Calc Tufa*. Travertine is of essentially the same origin with stalagmite, but is distinctively a deposit from springs or rivers, especially where in large deposits, as along the river Anio, at Tivoli, near Rome, where the deposit is scores of feet in thickness. Similar material is being deposited at the Mammoth Hot Springs, Yellowstone Park. (*d*) *Agaric mineral;* Rock-milk is a very soft white material, breaking easily in the fingers, deposited sometimes in caverns, or about sources holding lime in solution. (*e*) *Rock-meal* is white and light, like cotton, becoming a powder on the slightest pressure.

B. VARIETIES BASED UPON COMPOSITION

These include: *Dolomitic calcite.* Contains magnesium carbonate, thus graduating toward true dolomite. Also *baricalcite* (which contains some $BaCO_3$); similarly, *stron-*

tianocalcite ($SrCO_3$), *ferrocalcite* ($FeCO_3$), *manganocalcite* ($MnCO_3$) (see under *agnolite*, p. 582), *zincocalcite* ($ZnCO_3$), *plumbocalcite* ($PbCO_3$), *cobaltocalcite* ($CoCO_3$).

Pyr., etc. — B.B. infusible, glows, and colors the flame reddish yellow; after ignition the assay reacts alkaline; moistened with hydrochloric acid imparts the characteristic lime color to the flame. In the solid mass effervesces when moistened with hydrochloric acid, and fragments dissolve with brisk effervescence even in cold acid. See further under *aragonite*, p. 447.

Diff. — Distinguishing characters: perfect rhombohedral cleavage; softness, can be scratched with a knife; effervescence in cold dilute acid; infusibility. Less hard and of lower specific gravity than aragonite (which see). Resembles in its different varieties the other rhombohedral carbonates, but is less hard, of lower specific gravity, and more readily attacked by acid. Also resembles some varieties of barite, but has lower specific gravity; it is less hard than feldspar and harder than gypsum.

Micro. — Recognized in thin sections by its low refraction and very high birefringence, the polarization colors in the thinnest sections attaining white of the highest order. The negative interference figure, with many closely crowded colored rings, is also characteristic. The rhombohedral cleavage is often shown in the fine fracture lines; systems of twinned lamellæ often conspicuous (Fig. 750), especially in crystalline limestone.

Artif. — Crystals of calcite are formed when a solution of calcium carbonate in dilute carbonic acid is evaporated slowly at ordinary temperatures. Calcite is formed when aragonite is heated, the transformation being complete at 470°.

Obs. — Calcite, in its various forms, is one of the most widely distributed of minerals. Beds of sedimentary limestone, formed from organic remains, shells, crinoids, corals, etc., yield on metamorphism crystalline limestone or marble, and in connection with these crystallized calcite and also deposits in caves of stalactites and stalagmites often occur. Common with the zeolites in cavities and veins of igneous rocks as a result of alteration, and similarly though less abundant with granite, syenite, etc. A frequent mineral in metalliferous deposits, with lead, copper, silver, etc. Deposited from lime-bearing waters as calc sinter, travertine, etc., especially in connection with hot springs as at the Mammoth Hot Springs in the Yellowstone region.

Some of the best known localities for crystallized calcite are the following: Andreasberg in the Harz Mts.; the mines of Freiberg, Schneeberg, etc., in Saxony; Kapnik in Hungary; Aussig in Bohemia; Bleiberg in Carinthia; Traversella in Piedmont, Italy; Elba. In England at Alston Moor and Egremont in Cumberland; Matlock, Derbyshire; Beer Alston in Devonshire; at numerous points in Cornwall; Weardale in Durham; Stank mine, Lancashire. In twin crystals of great variety and beauty at Guanajuato, Mexico. The *Iceland spar* has been obtained from Iceland near Helgustadir on the Eskefiord. It occurs in a large cavity in basalt. The crystals, usually showing the fundamental rhombohedron, are often coated with tufts of stilbite.

In the United States, crystallized calcite occurs in N. Y., in St. Lawrence Co., especially at the Rossie lead mine; in Jefferson Co., near Oxbow; *dog-tooth spar*, in Niagara Co., near Lockport, with pearl spar, celestite, etc.; in Lewis Co., at Leyden and Lowville, and at the Martinsburg lead mine; at Anthony's Nose on the Hudson, formerly groups of large tabular crystals; twins from Union Springs, Cayuga Co. In N. J., at Bergen, yellow calcite with datolite, etc. In Va., at Wier's cave, *stalactites* of great beauty; also in the large caves of Ky. In pyramidal crystals from Kelly's Island, Lake Erie. At the Lake Superior copper mines, complex crystals often containing scales of native copper. At Warsaw, Ill., in great variety of form, lining geodes and implanted on quartz crystals; at Quincy. In Mo., with dolomite, near St. Louis; also with sphalerite at Joplin and other points in the zinc region in the south-western part of the state, the crystals usually scalenohedral and of a wine-yellow color. Wis., from Hazel Green. From the Bad Lands, S. D. In Nova Scotia, at Partridge Island, a wine-colored calcite, and other interesting varieties.

Use. — In the manufacture of mortars and cements; as a building and ornamental material; as a flux in metallurgical operations; Iceland spar is used to make polarizing prisms; chalk as a fertilizer, in whitewash, etc.

Thinolite. A tufa deposit of calcium carbonate occurring on an enormous scale in north-western Nev.; also occurs about Mono Lake, Cal. It forms layers of interlaced crystals of a pale yellow or light brown color and often skeleton structure except when covered by subsequent deposit of calcium carbonate.

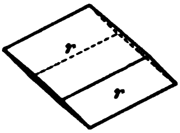
DOLOMITE. Pearl Spar pt.

Tri-rhombohedral. Axis $c = 0{\cdot}8322$.

cr, $0001 \wedge 10\bar{1}1 = 43° 52'$. MM', $40\bar{4}1 \wedge \bar{4}401 = 113° 53'$.
rr', $10\bar{1}1 \wedge \bar{1}101 = 73° 45'$.

Habit rhombohedral, usually $r(10\bar{1}1)$ or $M(40\bar{4}1)$; the presence of rhombohedrons of the second or third series after the phenacite type very characteristic. The r faces commonly curved or made up of subindividuals, and thus passing into saddle-shaped forms (Fig. 752).

751



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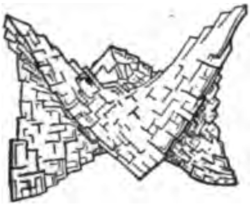

Also granular, coarse or fine, resembling ordinary marble.

Cleavage: $r(10\bar{1}1)$ perfect. Fracture subconchoidal. Brittle. H. = 3·5–4. G. = 2·8–2·9. Luster vitreous, inclining to pearly in some varieties. Color white, reddish, or greenish white; also rose-red, green, brown, gray and black. Transparent to translucent. Optically –. $\omega = 1{\cdot}68174$. $\epsilon = 1{\cdot}50256$.

Comp. — Carbonate of calcium and magnesium $(Ca,Mg)CO_3$; for normal dolomite $CaMgC_2O_6$ or $CaCO_3MgCO_3$ = Carbon dioxide 47·9, lime 30·4, magnesia 21·7 = 100, or Calcium carbonate 54·35, magnesium carbonate 45·65 = 100. Varieties occur in which the ratio of the two carbonates varies from 1 : 1. The carbonates of iron and manganese also frequently enter replacing the magnesium carbonate and grading to *ankerite;* rarely cobalt and zinc carbonates.

Pyr., etc. — B.B. acts like calcite. In solution gives tests for magnesium and usually for iron. Fragments thrown into cold acid, unlike calcite, are only very slowly acted upon, if at all, while in powder in warm acid the mineral is readily dissolved with effervescence. The ferriferous dolomites become brown on exposure.

Diff. — Resembles calcite (see p. 441), but generally to be distinguished in that it does not effervesce readily in the mass in cold acid.

Artif. — Artificial dolomite has been formed in several ways. The results of many experiments would indicate that heat and pressure are favorable for its formation. Sea water in contact with calcium carbonate when heated in a sealed tube produced dolomite. It has been observed that such reactions take place more readily with aragonite than with calcite, indicating the possibility of coral deposits (aragonite) being transformed into dolomite.

Micro. — Similar to calcite in thin sections except that it more often shows crystal outlines and less commonly polysynthetic twinning.

Obs. — Massive dolomite constitutes extensive strata, called limestone strata, in various regions, as in the dolomite region of the southern Tyrol. Crystalline and compact varieties are often associated with serpentine and other magnesian rocks, and with ordinary limestones. Dolomite, as a rock, is of secondary origin, having been transformed from ordinary limestone by the action of solutions containing magnesium. This change, called *dolomitization,* may take place in various ways. The more favorable conditions would involve heat, pressure, high magnesium content of waters and long periods of time. Consequently the older and more deeply buried in the earth's crust the greater is the probability of a limestone being converted into dolomite. Dolomite is also commonly a vein mineral, frequently occurring with various metallic ores. Some prominent localities are: Leogang in Salzburg, Austria; Schemnitz and Kapnik in Hungary; Freiberg in Saxony, Germany. In Switzerland, at Bex, in crystals; also in the Binnental; Traversella in Piedmont and Campolongo, Italy. In unusual dark colored crystals from Teruel, Spain.

In the United States, in Ver., at Roxbury. In N. J., at Hoboken. In N. Y. at Lockport, Niagara Falls, etc.; at the Tilly Foster iron mine, Brewster, Putnam Co., with magnetite, chondrodite. In Pa. at Phœnixville. In saddle-shaped crystals with the sphalerite of Joplin, Mo. In N. C. at Stony Point, Alexander Co. In fine crystals from Alamosa, Alaska.

Named after Dolomieu (1750–1801), who announced some of the marked characteristics of the rock in 1791 — its not effervescing with acids, while burning like limestone, and solubility after heating in acids.

Use. — As a building and ornamental stone; for the manufacture of certain cements; for the production of magnesia used in the preparation of refractory linings in metallurgical furnaces.

Ankerite. $CaCO_3.(Mg,Fe,Mn)CO_3$, or for normal ankerite $2CaCO_3.MgCO_3.FeCO_3$. In rhombohedral crystals; rr' $10\bar{1}1 \wedge \bar{1}101 = 73° 48'$ also crystalline massive, granular, compact. G. = 2·95–3·1. Color white, gray, reddish. Occurs with siderite at the Styrian mines. From Traversella, Italy. With the hematite of northern New York.

MAGNESITE.

Rhombohedral Axis: $c = 0·8112$. rr' $1011 \wedge \bar{1}101 = 72° 36'$. Crystals rare, usually rhombohedral, also prismatic. Commonly massive; granular cleavable to very compact; earthy.

Cleavage: $r(10\bar{1}1)$ perfect. Fracture flat conchoidal. Brittle. H. = 3·5–4·5. G. = 3·0–3·12, cryst. Luster vitreous; fibrous varieties sometimes silky. Color white, yellowish, or grayish white, brown. Transparent to opaque. Optically –. $\omega = 1·717$. $\epsilon = 1·515$.

Comp. — Magnesium carbonate, $MgCO_3$ = Carbon dioxide 52·4, magnesia 47·6 = 100. Iron carbonate is often present.

Breunnerite contains several p. c. of FeO; G. = 3–3·2; white, yellowish, brownish, rarely black and bituminous; often becoming brown on exposure, and hence called *Brown Spar*.

Pyr., etc. — B.B. resembles calcite and dolomite, and like the latter is but slightly acted upon by cold acids; in powder is readily dissolved with effervescence in warm hydrochloric acid. In solution gives strong test for magnesium with little or no calcium.

Obs. — Found as a secondary mineral formed by the alteration of various magnesian minerals; in talcose schist, serpentine and other magnesian rocks, also gypsum; as veins in serpentine, or mixed with it so as to form a variety of verd-antique marble. Occurs at Hrubschütz in Moravia; at Kraubat and Maria-Zell, Styria; Greiner in the Zillertal, Tyrol, Austria; Snarum, Norway.

In the United States, in Mass., at Bolton; at Roxbury, veining serpentine; in Md., at Barehills, near Baltimore; in Pa., in crystals, at West Goshen, Chester Co., near Texas, Lancaster Co.; in Cal. it is mined in Tulare, Kern, Santa Clara, Sonoma Cos. and elsewhere. A white saccharoidal magnesite resembling statuary marble has been found as loose blocks on an island in the St. Lawrence River, near the Thousand Island Park. In small prismatic crystals from Orangedale, Nova Scotia.

Use. — In the preparation of magnesite brick for the linings of metallurgical furnaces; in the manufacture of various chemical compounds, as epsom salts, magnesia, etc.

Intermediate between magnesite and siderite are:

MESITITE. $2MgCO_3.FeCO_3$. rr' $10\bar{1}1 \wedge \bar{1}101 = 72° 46'$. G. = 3·35–3·36. Usually in flat rhombohedrons (e, $01\bar{1}2$) with rounded faces. Traversella, Piedmont, Italy.

PISTOMESITE. $MgCO_3.FeCO_3$ = Magnesium carbonate 42·0, iron carbonate 58·0 = 100. rr' $10\bar{1}1 \wedge \bar{1}101 = 72° 42'$. G. = 3·42. Thurnberg, Salzburg, Austria; also Traversella, Italy.

SIDERITE. Chalybite, Spathic Iron.

Rhombohedral. Axis $c = 0·8184$.

cr, $0001 \wedge 10\bar{1}1 = 43° 23'$. rr', $10\bar{1}1 \wedge \bar{1}101 = 73° 0'$.
cM, $0001 \wedge 40\bar{4}1 = 75° 11'$. MM', $40\bar{4}1 \wedge \bar{4}401 = 113° 42'$.
cs, $0001 \wedge 05\bar{5}1 = 78° 3'$. ss', $05\bar{5}1 \wedge \bar{5}051 = 115° 50'$.
cd, $0001 \wedge 08\bar{8}1 = 82° 28'$. dd', $08\bar{8}1 \wedge \bar{8}081 = 118° 18\frac{1}{2}'$.

Crystals commonly rhombohedral r (1011) or e(0112) the faces often curved and built up of sub-individuals like dolomite. Often cleavable massive to coarse or fine granular. Also in botryoidal and globular forms, subfibrous within, occasionally silky fibrous; compact and earthy.

Cleavage: $r(10\bar{1}1)$ perfect. Fracture uneven or subconchoidal. Brittle. H. = 3·5–4. G. = 3·83–3·88. Luster vitreous, inclining to pearly. Color ash-gray, yellowish gray, greenish gray, also brown and brownish red, rarely green; and sometimes white. Streak white. Translucent to subtranslucent. Optically −. $\omega = 1{\cdot}873$. $\epsilon = 1{\cdot}633$.

Comp. — Iron protocarbonate, $FeCO_3$ = Carbon dioxide 37·9, iron protoxide 62·1 = 100 (Fe = 48·2 p. c.). Manganese may be present (as in *oligonite*, *manganospherite*), also magnesium and calcium.

Pyr., etc. — In the closed tube decrepitates, gives off CO_2, blackens and becomes magnetic. B.B. blackens and fuses at 4·5–5. With the fluxes reacts for iron, and with soda and niter on platinum foil generally gives a manganese reaction. Only slowly acted upon by cold acid, but dissolves with brisk effervescence in hot hydrochloric acid. Exposure to the atmosphere darkens its color, rendering it often of a blackish brown or brownish red color.

Diff. — Characterized by rhombohedral form and cleavage. Specific gravity higher than that of calcite, dolomite and ankerite. Resembles some sphalerite but lacks the resinous luster, differs in cleavage angle and yields CO_2 (not H_2S) with hydrochloric acid.

Obs. — Siderite may form as "bog ore" by the action, out of contact with the air, of organic matter in a bicarbonate solution. It may also be formed by the action of ferrous solutions upon limestones. It frequently occurs also as a vein mineral. It occurs in many of the rock strata, in gneiss, mica slate, clay slate, and as clay iron-stone in connection with the Coal formation and many other stratified deposits. It is often associated with metallic ores. At Freiberg, Saxony, it occurs in silver mines. In Cornwall it accompanies tin. It is also found accompanying copper and iron pyrites, galena, chalcocite, tetrahedrite. Occasionally it is to be met with in trap rocks as *spherosiderite* in globular concretions. Extensive deposits occur in the Eastern Alps, in Styria and Carinthia at Tavetsch, Switzerland. At Harzgerode and elsewhere in the Harz Mts., it occurs in fine crystals in gray-wacke; also in Cornwall of varied habit at many localities; at Alston-Moor, and Tavistock, Devonshire. In large rhombohedrons from Allevard, France. Fine cleavage masses occur with cryolite in Greenland.

In the United States, in Ver., at Plymouth. In Mass., at Sterling. In Conn., at Roxbury, an extensive vein in quartz, traversing gneiss. In N. Y., a series of deposits occur in Columbia Co.; at the Rossie iron mines, St. Lawrence Co. In N. C., at Fentress and Harlem mines. The argillaceous carbonate, in nodules and beds (clay ironstone), is abundant in the coal regions of Pa., Ohio, and many parts of the country. In a clay-bed under the Tertiary along the west side of Chesapeake Bay for 50 m.

Use. — An ore of iron.

RHODOCHROSITE. Dialogite.

Rhombohedral. Axis $c = 0{\cdot}8184$, rr' $10\bar{1}1 \wedge \bar{1}101 = 73°\ 0'$. Distinct crystals not common; usually the rhombohedron $r(10\bar{1}1)$; also $e(01\bar{1}2)$, with rounded striated faces. Cleavable, massive to granular-massive and compact. Also globular and botryoidal, with columnar structure, sometimes indistinct; incrusting.

Cleavage: $r(10\bar{1}1)$ perfect. Fracture uneven. Brittle. H. = 3·5–4·5. G. = 3·45–3·60 and higher. Luster vitreous, inclining to pearly. Color shades of rose-red; yellowish gray, fawn-colored, dark red, brown. Streak white. Translucent to subtranslucent. Optically −. $\omega = 1{\cdot}820$. $\epsilon = 1{\cdot}600$.

Comp. — Manganese protocarbonate, $MnCO_3$ = Carbon dioxide 38·3, manganese protoxide 61·7 = 100. Iron carbonate is usually present even up to 40 p. c , as in *manganosiderite;* sometimes the carbonate of calcium, as in *manganocalcite*, also magnesium, zinc, and rarely cobalt.

Pyr., etc. — B.B. changes to gray, brown, and black, and decrepitates strongly, but is infusible. With salt of phosphorus and borax in O.F. gives an amethystine-colored bead, in R.F. becomes colorless. With soda in O.F. a bluish green manganate. Dissolves with effervescence in warm hydrochloric acid. On exposure to the air changes to brown, and some bright rose-red varieties become paler.

Diff. — Characterized by its pink color, rhombohedral form and cleavage, effervescence in acids.

Obs. — Occurs commonly in veins along with ores of silver, lead and copper, and with other ores of manganese. Found at Schemnitz and Kapnik in Hungary; Nagyág in Transylvania; *ponite* is a ferriferous variety from Roumania; in Germany at Freiberg in Saxony; at Diez near Oberneisen in Nassau; at Daaden, Rheinprovinz; in Belgium at Moet-Fontaine in the Ardennes. A variety containing 45 per cent of zinc carbonate from Rosseto, Elba, has been called *zincorodochrosite*. In the United States at Branchville, Conn.; in N. J., with franklinite at Mine Hill, Franklin Furnace. In Col., at the John Reed mine, Alicante, Lake Co., in beautiful clear rhombohedrons; also at the Oulay mine, near Lake City and Alma, Park Co.; in Chaffee, Gilpin and Ouray Cos. In Mon., at Butte City. Abundant at the silver mines of Austin, Nev. At Placentia Bay, Newfoundland.

Named *rhodochrosite* from *ρόδον*, *a rose*, and *χρῶσις*, *color;* and *dialogite*, from *διαλογή*, *doubt*.

Use. — A minor ore of manganese.

SMITHSONITE. Calamine pt. Dry-bone ore *Miners*.

Rhombohedral. Axis $c = 0{\cdot}8063$. rr' $10\bar{1}1 \wedge \bar{1}101 = 72° 20'$. Rarely well crystallized; faces $r(10\bar{1}1)$ generally curved and rough. Usually reniform, botryoidal, or stalactitic, and in crystalline incrustations; also granular, and sometimes impalpable, occasionally earthy and friable.

Cleavable: $r(10\bar{1}1)$ perfect. Fracture uneven to imperfectly conchoidal. Brittle. H. = 5. G. = 4·30–4·45. Luster vitreous, inclining to pearly. Streak white. Color white, often grayish, greenish, brownish white, sometimes green, blue and brown. Subtransparent to translucent. Optically –. $\omega = 1{\cdot}818$. $\epsilon = 1{\cdot}618$.

Comp. — Zinc carbonate, $ZnCO_3$ = Carbon dioxide 35·2, zinc protoxide 64·8 = 100. Iron carbonate is often present (as in *monheimite*); also manganese and cobalt carbonates; further calcium and magnesium carbonates in traces; rarely cadmium and indium.

Pyr., etc. — In the closed tube loses carbon dioxide, and, if pure, is yellow while hot and white on cooling. B.B. infusible, giving characteristic zinc flame; moistened with cobalt solution and heated in O.F. gives a green color on cooling. With soda on charcoal coats the coal with the oxide, which is yellow while hot and white on cooling; this coating, moistened with cobalt solution, gives a green color after heating in O.F. Soluble in hydrochloric acid with effervescence.

Diff. — Distinguished from calamine, which it often closely resembles, by its effervescence in acids.

Obs. — Found both in veins and beds, especially in company with galena and sphalerite; also with copper and iron ores. It usually occurs in calcareous rocks, and is generally associated with calamine, and sometimes with limonite. It frequently replaces limestone, pseudomorphs after calcite crystals being often observed. Commonly a secondary mineral and is often produced by the action of carbonated waters upon zinc sulphide. Often is in a porous, honey-comb-like material, known commonly as "dry-bone" ore.

Found at Nerchinsk in Siberia; at Dognaczka in Hungary; Bleiberg and Raibel in Carinthia; Wiesloch in Baden and at Altenberg, Germany. Moresnet in Belgium and Altenberg. In the province of Santander, Spain, at Puente Viesgo. In England, at Roughten Gill, Alston Moor, near Matlock, in the Mendip Hills, and elsewhere; in Ireland, at Donegal. At Laurion, Greece, varieties of many colors; from Sardinia. From Broken Hill, New South Wales.

In the United States, in Pa., at Lancaster abundant, the variety called "dry-bone"; at the Ueberroth mine, near Bethlehem, in scalenohedrons. In Wis., at Mineral Point, Shullsburg, etc., pseudomorphs after sphalerite and calcite. In Ia., at Ewing's diggings, N. W. of Dubuque, etc. In south-western Mo., associated with sphalerite and calamine. In Ark., at Calamine, Lawrence Co.; in Marion Co. A pink cobaltiferous variety occurs at Boleo, Lower California. In N. M. from Socorro Co. and in translucent green botryoidal masses from Kelly. In Tooele Co., Utah.

Named after James Smithson (1754–1829), who founded the Smithsonian Institution in Washington. The name calamine is frequently used in England, cf. calamine, p. 539.

Use. — An ore of zinc.

Sphærocobaltite. Cobalt protocarbonate, $CoCO_3$. Rhombohedral. In small spherical masses, with crystalline surface, rarely in crystals. G. = 4·02–4·13. Color rose-red. From Schneeberg, Saxony. From Boleo, Lower California.

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2. *Aragonite Group.* RCO_3. Orthorhombic

For list of species, see p. 437.

ARAGONITE.

Orthorhombic. Axes $a : b : c = 0{\cdot}62244 : 1 : 0{\cdot}72056$.

mm''', $110 \wedge 1\bar{1}0 = 63° 48'$.
kk', $011 \wedge 0\bar{1}1 = 71° 33'$.
pp', $111 \wedge \bar{1}11 = 86° 24\tfrac{1}{2}'$.
pp''', $111 \wedge 1\bar{1}1 = 50° 27'$.

Crystals often acicular, and characterized by the presence of acute domes or pyramids. Twins: tw. pl. $m(110)$ commonly repeated, producing pseudo-hexagonal forms (see Figs. 755–757). Also globular, reniform, and coralloidal shapes; sometimes columnar, straight or divergent; also stalactitic; incrusting.

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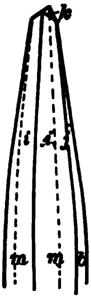

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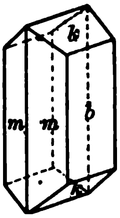

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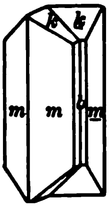

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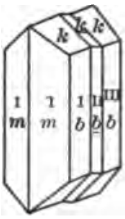

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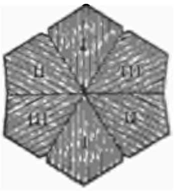

Cleavage: $b(010)$ distinct; also $m(110)$; $k(011)$ imperfect. Fracture subconchoidal. Brittle. H. = 3·5–4. G. = 2·93–2·95. Luster vitreous, inclining to resinous on surfaces of fracture. Color white; also gray, yellow, green and violet; streak uncolored. Transparent to translucent. Optically −. Ax. pl. || $a(100)$. Bx ⊥ $c(001)$. Dispersion $\rho > v$ small. $2E = 30° 54'$. $\alpha = 1{\cdot}531$. $\beta = 1{\cdot}682$. $\gamma = 1{\cdot}686$.

Comp. — Calcium carbonate, $CaCO_3$ = Carbon dioxide 44·0, lime 56·0 = 100. Some varieties contain a little strontium, others lead, and rarely zinc.

Aragonite changes to calcite at 470°.

Var. — *Ordinary.* (*a*) Crystallized in simple or compound crystals, the latter much the most common; often in radiating groups of acicular crystals. Columnar; also fine fibrous with silky luster. (*c*) Massive.

Stalactitic or *stalagmitic:* Either compact or fibrous in structure, as with calcite; *Sprudelstein* is stalactitic from Carlsbad, Bohemia. *Coralloidal:* In groupings of delicate interlacing and coalescing stems, of a snow-white color, and looking a little like coral; often called *Flosferri*. *Tarnowitzite* is a kind containing lead carbonate (4 to 8 p. c.), from Tarnowitz in Silesia; with G. = 2·99. *Zeyringite* is a calcareous sinter, probably aragonite, colored greenish white or sky-blue with nickel, from Zeyring, Styria. *Nicholsonite* is aragonite containing zinc from Leadville, Col., and the Tintic District, Utah.

Pyr., etc. — B.B. whitens and falls to pieces, and sometimes, when containing strontia, imparts a more intensely red color to the flame than lime; otherwise reacts like calcite. When immersed in cobalt nitrate solution powder turns lilac and the color persists on boiling while calcite under like conditions remains uncolored or becomes blue on long boiling. It is stated that these tests are not always strictly reliable.

Diff. — Distinguished from calcite by higher specific gravity and absence of rhombohedral cleavage; from the zeolites (*e.g.*, natrolite), etc., by effervescence in acid. Strontianite and witherite are fusible, higher in specific gravity and yield distinctive flames B.B. The resinous luster on fracture surfaces is to be noted.

Artif. — Aragonite will form when solutions of calcium carbonate are evaporated at temperatures from 80° to 100°; it will form at lower temperatures if the solution contains some sulphate or small amounts of the carbonates of strontium or lead.

Obs. — The most common repositories of aragonite are beds of gypsum; also beds of iron ore, as the Styrian mines, where it occurs in coralloidal forms, and is denominated *flosferri*, "*flower of iron*"; in cavities in basalt and lavas; often associated with copper and iron pyrites, galena, and malachite. It constitutes the pearly layer of shells and the skeleton material of corals.

First discovered in Aragon, Spain (whence its name), at Molina and Valencia, in six-sided prisms, with gypsum, similarly at Dax, France. Prominent localities are Bilin, Bohemia; Racanbunto, Silesia; Leogang in Salzburg, Austria; Herrengrund, Hungary; with sulphur in Sicily in fine prisms; also at Alston Moor and elsewhere, England, fine tapering crystals. In twins frequently replaced by native copper from Coro-Coro, Bolivia.

In fibrous crusts at Hoboken, N. J.; at Edenville and Rossie, N. Y.; Wood's Mine, Lancaster Co., Pa.; Warsaw, Ill., lining geodes; Mine-la-Motte, Mo., in crystals. *Flosferri* in the Organ Mts., N. M.; from Bisbee, Ariz.

Ktypeite is calcium carbonate in the form of pisolites from Carlsbad, Bohemia, and Hammam-Meskoutine, Algeria. G. = 2·58–2·70. Decrepitates when heated and changes to calcite.

WITHERITE.

Orthorhombic. Axes *a* : *b* : *c* = 0·6032 : 1 : 0·7302. Crystals always repeated twins, simulating hexagonal pyramids. Also massive, columnar or granular.

Cleavage: *b*(010) distinct; *m*(110) imperfect. Fracture uneven. Brittle. H. = 3–3·75. G. = 4·27–4·35. Luster vitreous, inclining to resinous on surfaces of fracture. Color white, yellowish, grayish. Streak white. Subtransparent to translucent. Optically –. $\alpha = 1{\cdot}529$. $\beta = 1{\cdot}676$. $\gamma = 1{\cdot}677$.

Comp. — Barium carbonate, $BaCO_3$ = Carbon dioxide 22·3, baryta 77·7 = 100.

Pyr., etc. — B.B. fuses at 2 to a bead, coloring the flame yellowish green; after fusion reacts alkaline. B.B. on charcoal with soda fuses easily, and is absorbed by the coal. Soluble in dilute hydrochloric acid; this solution, even when very much diluted, gives with sulphuric acid a white precipitate which is insoluble in acids.

Diff. — Distinguished by its high specific gravity; effervescence in acid; green coloration of the flame B.B. Barite is insoluble in hydrochloric acid.

Obs. — Occurs at Alston Moor in Cumberland, with galena; at Fallowfield near Hexham in Northumberland; Tarnowitz in Silesia. Leogang in Salzburg, Austria. Near Lexington, Ky., with barite. In a silver-bearing vein near Rabbit Mt., Thunder Bay, Lake Superior. From Tsubaki mine, Prov. Ugo, Japan.

Use. — A minor source of barium compounds.

Bromlite. $(Ba,Ca)CO_3$. In pseudohexagonal pyramids (Figs. 611, 612, p. 299). Indices, 1·525–1·670. Bromley Hill, near Alston, Cumberland, England.

STRONTIANITE.

Orthorhombic. Axes *a* : *b* : *c* = 0·6090 : 1 : 0·7239.

Crystals often acicular or acute spear-shaped, like aragonite. Twins: tw. pl. *m*(110) common. Also columnar, fibrous and granular.

Cleavage: *m*(110) nearly perfect; *b*(010) in traces. Fracture uneven. Brittle. H. = 3·5–4. G. = 3·680–3·714. Luster vitreous; inclining to resinous on faces of fracture. Color pale asparagus-green, apple-green; also white, gray, yellow, and yellowish brown. Streak white. Transparent to translucent. Optically –. Ax. pl. || *b*(010). Bx ⊥ *c*(001). Dispersion $\rho < v$ small. $2E_r = 12° 17'$. $\alpha = 1·520$. $\beta = 1·667$. $\gamma = 1·667$.

Comp. — Strontium carbonate, $SrCO_3$ = Carbon diozide 29·9, strontia 70·1 = 100. A little calcium is sometimes present.

Pyr., etc. — B.B. swells up, throws out minute sprouts, fuses only on the thin edges, and colors the flame strontia-red; the assay reacts alkaline after ignition. Moistened with hydrochloric acid and treated either B.B. or in the naked lamp gives an intense red color. Soluble in hydrochloric acid; the mediumly dilute solution when treated with sulphuric acid gives a white precipitate.

Diff. — Differs from related minerals, not carbonates, in effervescing with acids; has a higher specific gravity than aragonite and lower than witherite; colors the flame *red* B.B.

Obs. — Occurs at Strontian in Argyllshire and in Yorkshire, England; Claustal in the Harz Mts., Germany; Bräunsdorf, near Freiberg, Saxony; Leogang in Salzburg, Austria; near Brixlegg, Tyrol, Austria (*calciostrontianite*); in Westphalia, Germany in fine crystals near Hamm, and at the Wilhelmine mine near Altahlen.

In the United States, occurs in N. Y. at Schoharie, at Muscalonge Lake, Chaumont Bay and Theresa, in Jefferson Co.; Mifflin Co., Pa.

Use. — A minor source of strontium compounds.

CERUSSITE. White Lead Ore.

Orthorhombic. Axes $a : b : c = 0·60997 : 1 : 0·72300$.

mm''', $110 \wedge 1\bar{1}0 = 62° 46'$.
kk', $011 \wedge 0\bar{1}1 = 71° 44'$.
ii', $021 \wedge 0\bar{2}1 = 110° 40'$.
cp, $001 \wedge 111 = 54° 14'$.
pp', $111 \wedge \bar{1}11 = 87° 42'$.
pp''', $111 \wedge 1\bar{1}1 = 49° 59\frac{1}{2}'$.

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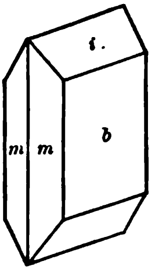

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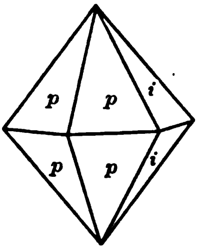

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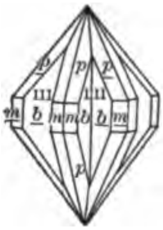


Simple crystals often tabular || *b*(010), prismatic || *c* axis; also pyramidal. Twins: tw. pl. *m*(110) very common, contact- and penetration-twins, often repeated yielding six-rayed stellate groups. Crystals grouped in clusters, and aggregates. Rarely fibrous, often granular massive and compact; earthy. Sometimes stalactitic.

Cleavage: *m*(110) and *i*(021) distinct; *b*(010) and *x*(012) in traces. Fracture conchoidal. Very brittle. H. = 3–3·5. G. = 6·46–6·574. Luster adamantine, inclining to vitreous, resinous, or pearly; sometimes submetallic. Color white, gray, grayish black, sometimes tinged blue or green (copper); streak uncolored. Transparent to subtranslucent. Optically –. Ax. pl. || *b*(010). Bx ⊥ *c*(001). Dispersion $\rho > v$ large. 2 V = 8° 14′. $\alpha = 1·804$. $\beta = 2·076$. $\gamma = 2·078$.

Comp. — Lead carbonate, $PbCO_3$ = Carbon dioxide 16·5, lead oxide 83.5 = 100.

Pyr., etc. — In the closed tube decrepitates, loses carbon dioxide, turns first yellow, and at a higher temperature dark red, but becomes again yellow on cooling. B.B. on charcoal fuses very easily, and in R.F. yields metallic lead. Soluble in dilute nitric acid with effervescence.

Diff. — Characterized by high specific gravity and adamantine luster; also by yielding lead B.B. Unlike anglesite, it effervesces with nitric acid.

Artif. — Cerussite has been produced artificially by the slow diffusion of a carbonate solution into a lead solution through a porous membrane; by the action of a carbonate solution upon a lead plate.

Obs. — A secondary mineral occurring in connection with other lead minerals, and is formed from galena, which, as it passes to a sulphate, may be changed to carbonate by means of solutions of calcium bicarbonate. It is found in Germany at Johanngeorgenstadt in beautiful crystals; Friedrichssegen, Nassau; Badenweiler, Baden; at Claustal in the Harz Mts. Other important localities are Monte Poni, Sardinia; at Bleiberg in Carinthia; at Mies and Přibram, Bohemia; in England, in Cornwall; at East Tamar mine, Devonshire; near Matlock and Wirksworth, Derbyshire; at Leadhill and Wanlockhead, Scotland. Fine crystals from Broken Hill, New South Wales.

Found in Pa., at Phenixville. In Va., at Austin's mines, Wythe Co. In N. C., in King's mine. In lead mines of Wis. but rarely in crystals; at Hazelgreen, crystals coating galena. In Col., at Leadville, and elsewhere. In Ariz., at the Flux mine, Pima Co., in large crystalline masses; in crystals at the Red Cloud mine, Yuma Co. In Utah from Flagstaff mine; in Idaho at Wardner and Kingston.

Use. — An ore of lead.

BARYTOCALCITE.

Monoclinic. Axes $a : b : c = 0{\cdot}7717 : 1 : 0{\cdot}6254$; $\beta = 73^\circ\ 52'$. In crystals; also massive.

Cleavage: $m(110)$ perfect; $c(001)$ less so. Fracture uneven to subconchoidal. Brittle. H. = 4. G. = 3·64–3·66. Luster vitreous, inclining to resinous. Color white, grayish, greenish or yellowish. Streak white. Transparent to translucent. Optically −. $\alpha = 1{\cdot}525$. $\beta = 1{\cdot}684$. $\gamma = 1{\cdot}686$.

Comp. — Carbonate of barium and calcium, $BaCO_3.CaCO_3$ = Carbon dioxide 29·6, baryta 51·5, lime 18·9 = 100.

Pyr., etc. — B.B. colors the flame yellowish green, and at a high temperature fuses on the thin edges and assumes a pale green color; the assay reacts alkaline after ignition. Soluble in dilute hydrochloric acid with effervescence. Dilute solution gives an abundant precipitate, $BaSO_4$, with a few drops of sulphuric acid.

Obs. — Occurs at Alston Moor in Cumberland, England, in limestone with barite and fluorite.

Rosasite. $2CuO.3CuCO_3.5ZnCO_3$?. Mammillary fibrous of a bright green to sky-blue color. From Rosas mine at Sulcis, Sardinia.

Bismutosphärite. $Bi_2(CO_3)_3.2Bi_2O_3$. In spherical forms with radiated structure. G. = 7·42. Color yellow to gray or blackish brown. From Schneeberg, Saxony. Also sparingly at Willimantic and Portland, Conn., as a result of the alteration of bismuthinite. From the Stewart mine, Pala, San Diego Co., Cal.

Rutherfordine. Uranyl carbonate, UO_2CO_3. A yellow ocher resulting from alteration of uraninite. G. = 4·8. From Uruguru Mts., German East Africa.

Parisite. A fluocarbonate of the cerium metals, $[(Ce,La,Di)F]_2Ca(CO_3)_3$. Rhombohedral. Crystals small and slender. Habit pyramidal or prismatic. Crystals horizontally grooved due to oscillatory combination of faces. H. = 4·5. G. = 4·358. Color brownish yellow. Optically +. $\omega = 1{\cdot}676$. $\epsilon = 1{\cdot}757$. From the emerald mines, Muso, Colombia; Ravalli, Mon.; Quincy, Mass.; Montorfano, Italy; Narsarsuk, Greenland (*synchisite*).

Cordylite is a parisite containing barium from Narsarsuk, South Greenland. Other material from Narsarsuk thought to be a new species and named *synchisite* is parisite.

Bastnäsite. Hamartite. A fluocarbonate of the cerium metals $(RF)CO_3$. H. = 4·5. G. = 4·948. Color wax-yellow to reddish brown. Uniaxial, +. Strong birefringence. $\omega = 1{\cdot}715$. From the Bastnäs mine, Riddarhyttan, Sweden. Also in parallel growth with tysonite in the granite of the Pike's Peak region in Colorado. Found to the east of Ambositra, Madagascar.

Ancylite. $4Ce(OH)CO_3.3SrCO_3.3H_2O$. Orthorhombic. In small pyramids with curved faces and edges. H. = 4·5. G. = 3·9. Color light yellow, orange, brown, gray. Infusible. From Narsarsuk, Greenland. *Weibyeïte* is a related mineral.

Ambatoarinite. A carbonate of strontium and the rare earths. Orthorhombic? In crystals with parallel axes, forming skeleton-like groups. Index, > 1·66. From Ambatoarina, near Ambositra, Madagascar.

PHOSGENITE.

Tetragonal. Axis c = 1·0876. Crystals prismatic; sometimes tabular || c(001).

Cleavage: m(110), a(100) distinct; also c(001). Rather sectile. H. = 2·75–3. G. = 6·0–6·3. Luster adamantine. Color white, gray, and yellow. Streak white. Transparent to translucent. Optically +. ω = 2·114. ϵ = 2·140.

Comp. — Chlorocarbonate of lead, $(PbCl)_2CO_3$ or $PbCO_3.PbCl_2$ = Lead carbonate 49·0, lead chloride 51·0 = 100.

Pyr., etc. — B.B. melts readily to a yellow globule, which on cooling becomes white and crystalline. On charcoal in R.F. gives metallic lead, with a white coating of lead chloride. Dissolves with effervescence in dilute nitric acid and solution reacts for chlorine with silver nitrate.

Obs. — At Cromford near Matlock in Derbyshire; at Gibbas, Monte Poni and Montevecchio in Sardinia. From Broken Hill, New South Wales; Dundas, Tasmania.

Northupite. $MgCO_3.Na_2CO_3.NaCl$. In isometric octahedrons. H. = 3·5–4. G. = 2·38. White to yellow or gray. n = 1·514. From Borax Lake, San Bernardino Co., Cal.

Tychite. $2MgCO_3.2Na_2CO_3.Na_2SO_4$. Isometric. Octahedral habit. H. = 3·5. G. = 2·5. n = 1·51. Very rare. From Borax Lake, San Bernardino Co., Cal., associated with northupite.

B. ACID, BASIC, AND HYDROUS CARBONATES

Teschemacherite. Acid ammonium carbonate, HNH_4CO_3. Orthorhombic. In yellowish to white crystals. G. = 1·45. Indices, 1·423–1·536. From guano deposits of Africa, Patagonia, the Chincha Islands.

MALACHITE.

Monoclinic. Axes $a : b : c$ = 0·8809 : 1 : 0·4012; β = 61° 50′.

Crystals rarely distinct, usually slender, acicular prisms (mm''' 110 $\wedge$ $1\bar{1}0$ = 75° 40′), grouped in tufts and rosettes. Twins: tw. pl. a(100) common. Commonly massive or incrusting, with surface botryoidal, or stalactitic, and structure divergent; often delicately compact fibrous, and banded in color; frequently granular or earthy.

Cleavage: c(001) perfect; b(010) less so. Fracture subconchoidal, uneven. Brittle. H. = 3·5–4. G. = 3·9–4·03. Luster of crystals admantine, inclining to vitreous; of fibrous varieties more or less silky; often dull and earthy. Color bright green. Streak paler green. Translucent to subtranslucent to opaque. Optically −. β = 1·88.

Comp. — Basic cupric carbonate, $CuCO_3.Cu(OH)_2$ = Carbon dioxide 19·9, cupric oxide 71·9, water 8·2 = 100.

Pyr., etc. — In the closed tube blackens and yields water. B.B. fuses at 2, coloring the flame emerald-green; on charcoal is reduced to metallic copper; with the fluxes reacts like cuprite. Soluble in acids with effervescence.

Diff. — Characterized by green color and copper reactions B.B.; differs from other copper ores of a green color in its effervescence with acids.

Artif. — Malachite has been formed artificially by heating precipitated copper carbonate with a solution of ammonium carbonate for several days.

Obs. — Common with other ores of copper and as a product of their alteration; thus as a pseudomorph after cuprite and azurite. Occurs abundantly in the Ural Mts.; at Chessy in France; in Cornwall and in Cumberland, England; in Germany at Rheinbreitbach; Dillenburg, Nassau; Betzdorf near Siegen. At the copper mines of Nizhni Tagilsk, Russia; with the copper ores of Cuba; Chile; at the Cobar mines and elsewhere in New South Wales; South Australia; Rhodesia. In crystals from Katanga, Congo, and Mindouli, French Congo.

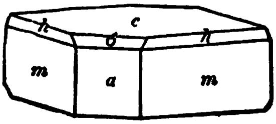
Occurs in N. J., at Schuyler's mines, and at New Brunswick. In Pa., at Cornwall, Lebanon Co.; at the Perkiomen and Phenixville lead-mines. In Wis., at the copper mines, of Mineral Point, and elsewhere. Abundantly in fine masses and acicular crystals, with calcite at the Copper Queen mine, Bisbee, Cochise Co., Ariz.; also in Graham Co., at Morenci (6 m. from Clifton), in stalactitic forms of malachite and azurite in concentric bands. At the Santa Rita mines, Grant Co., and elsewhere in N. M. Tintic district, Utah. In pseudomorphs from Good Springs, Nev. Named from *μαλαχή*, *mallows*, in allusion to the green color.

Use. — An ore of copper; at times as an ornamental stone.

AZURITE.

Monoclinic. Axes $a : b : c = 0{\cdot}8501 : 1 : 0{\cdot}8805$; $\beta = 87° 36'$.

761



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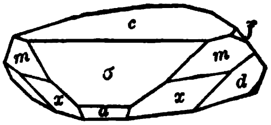

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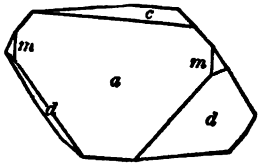

mm''', $110 \wedge 1\bar{1}0 = 80° 41'$.
ac, $100 \wedge 001 = 87° 36'$.
cσ, $001 \wedge 101 = 44° 46'$.
ll', $023 \wedge 0\bar{2}3 = 60° 47'$.
pp', $021 \wedge 0\bar{2}1 = 120° 47'$.
cm, $001 \wedge 110 = 88° 10'$.
cd, $001 \wedge \bar{2}43 = 54° 29'$.
hh', $221 \wedge 2\bar{2}1 = 73° 56'$.

Crystals varied in habit and highly modified. Also massive, and presenting imitative shapes, having a columnar composition; also dull and earthy.

Cleavage: *p*(021) perfect but interrupted; *a*(100) less perfect; *m*(110) in traces. Fracture conchoidal. Brittle. H. = 3·5–4. G. = 3·77–3·83. Luster vitreous, almost adamantine. Color various shades of azure-blue, passing into Berlin-blue. Streak blue, lighter than the color. Transparent to subtranslucent. $\alpha = 1{\cdot}730$. $\beta = 1{\cdot}758$. $\gamma = 1{\cdot}838$.

Comp. — Basic cupric carbonate, $2CuCO_3.Cu(OH)_2$ = Carbon dioxide 25·6, cupric oxide 69·2, water 5·2 = 100.

Pyr., etc. — Same as in malachite.

Diff. — Characterized by its blue color; effervescence in nitric acid; copper reactions B.B.

Artif. —Azurite has been formed by allowing a solution of copper nitrate to lie in contact with fragments of calcite for several years.

Obs. — Occurs in splendid crystallizations in France at Chessy, near Lyons, whence it derived the name *Chessy Copper* or *chessylite*. Also in fine crystals in Siberia; Moldawa in the Banat, Hungary; at Wheal Buller, near Redruth in Cornwall; in Devonshire and Derbyshire, England; at Broken Hill and elsewhere in New South Wales; South Australia.

Occurs in Pa., at Phenixville, in crystals. In N. J., near New Brunswick. In Wis., near Mineral Point. In Ariz., at the Longfellow and other mines in Graham Co.; with malachite in beautiful crystals at the Copper Queen mine, Bisbee; at Morenci. In Grant Co., N. M. At the Mammoth mine in the Tintic district and in Tooele Co., Utah. In Cal., Calaveras Co., at Hughes's mine, in crystals.

Use. — An ore of copper.

Aurichalcite. A basic carbonate of zinc and copper, $2(Zn,Cu)CO_3.3(Zn,Cu)(OH)_2$. Orthorhombic? In drusy incrustations. G. = 3·54–3·64. Luster pearly. Color pale green to sky-blue. Indices, 1·634–1·682. From the Altai Mts., Mongolia; Chessy, near Lyons, France; Rezbánya, Hungary; Ondárroa, Vizcaya, Spain; Chihuahua, Mexico. In the United States, at Lancaster, Pa.; Salida, Col.; the Santa Caterina Mts., Ariz.; Beaver Co., Utah; Kelly, N. M.

Hydrozincite. A basic zinc carbonate, perhaps $ZnCO_3.2Zn(OH)_2$. Massive, fibrous, earthy or compact, as incrustations. G. = 3·58–3·8. Color white, grayish or yellowish.

Index, 1·695. Occurs at mines of zinc, as a result of alteration. In great quantities at the Dolores mine, Santander, Spain. From Chihuahua, Mexico; Bleyberg, Belgium; Malfidano, Sardinia. In the United States at Friedensville, Pa.; at Linden, in Wis.; Granby, Mo.

OTAVITE. A basic cadmium carbonate of uncertain composition. In crusts showing minute rhombohedral crystals. Color white to reddish. From the Otavi district, German Southwest Africa.

Hydrocerussite. A basic lead carbonate, probably $2PbCO_3.Pb(OH)_2$. In thin colorless hexagonal plates. Index, 2·07. Occurs as a coating on native lead, at Långban, Sweden; with galena at Wanlockhead, Scotland.

Dundasite. A basic carbonate of lead and aluminium, $Pb(AlO)_2(CO_3)_2.4H_2O$. In small spherical aggregates of radiating acicular crystals. Color white. From Dundas and Mt. Read, Tasmania, and from near Trefriw, Carnarvonshire, Wales; Wensley, Derbyshire; near Maam, County Galway, Ireland.

Dawsonite. A basic carbonate of aluminium and sodium, $Na_3Al(CO_3)_3.2Al(OH)_3$. Orthorhombic. In thin incrustations of white radiating bladed crystals. Perfect cleavage, *m* (110). G. = 2·40. Indices, 1·466–1·596. Found on a feldspathic dike near McGill College, Montreal. From the province of Siena, Pian Castagnaio, Tuscany, Italy

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Thermonatrite. Hydrous sodium carbonate, $Na_2CO_3.H_2O$. G. = 1·5–1·6. Occurs in various lakes, and as an efflorescence over the soil in many dry regions.

Nesquehonite. Hydrous magnesium carbonate, $MgCO_3.3H_2O$. In radiating groups of prismatic crystals. G. = 1·83–1·85. Colorless to white. Biaxial, –. Indices, 1·495–1·526. From a coal mine at Nesquehoning, Schuylkill Co., Pa. See lansfordite, p. 453.

Natron. Hydrous sodium carbonate, $Na_2CO_3.10H_2O$. Occurring in nature only in solution, as in the soda lakes of Egypt, and elsewhere, or mixed with the other sodium carbonates.

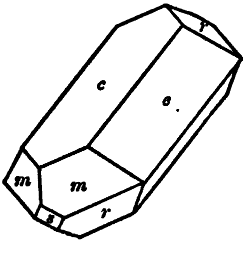
Pirssonite. $CaCO_3.Na_2CO_3.2H_2O$. In prismatic crystals, orthorhombic-hemimorphic. H. = 3. G. = 2·35. Colorless to white. Optically +. Indices, 1·504–1·575. Borax Lake, San Bernardino, Cal.

GAY-LUSSITE.

Monoclinic. Axes $a : b : c = 1·4897 : 1 : 1·4442$; $\beta = 78° 27'$.

mm''', $110 \wedge 1\bar{1}0 = 111° 10'$.
ee', $011 \wedge 0\bar{1}1 = 109° 30'$.
me, $110 \wedge 011 = 42° 21'$.
rr', $\bar{1}12 \wedge \bar{1}\bar{1}2 = 69° 29'$.

764



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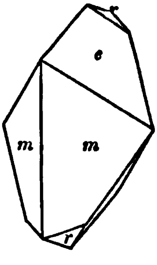


Crystals often elongated || *a* axis; also flattened wedge-shaped. Cleavage: *m* (110) perfect; *c* (001) rather difficult. Fracture conchoidal. Very brittle. H. = 2–3. G. = 1·93–1·95. Luster vitreous. Color white, yellowish white. Streak uncolored to grayish. Translucent. Optically –. $\alpha = 1·444$, $\beta = 1·517$., $\gamma = 1·518$.

Comp. — Hydrous carbonate of calcium and sodium, $CaCO_3.Na_2CO_3.5H_2O$ = Calcium carbonate 33·8, sodium carbonate 35·8, water 30·4 = 100.

Pyr., etc. — Heated in a closed tube decrepitates and becomes opaque. B.B. fuses easily to a white enamel, and colors the flame intensely yellow. Dissolves in acids with a brisk effervescence; partly soluble in water, and reddens turmeric paper.

Obs. — Abundant at Lagunilla, near Merida, in Venezuela, in crystals disseminated at the bottom of a small lake, in a bed of clay, covering *trona*. Also abundant in Little Salt Lake, or Soda Lake, in the Carson desert near Ragtown, Nev., deposited upon the evaporation of the water. From Sweetwater Valley, Wy. Named after Gay Lussac, the French chemist (1778–1850).

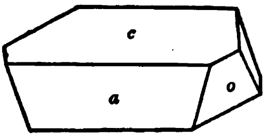
Lanthanite. $La_2(CO_3)_3.9H_2O$. In thin tabular orthorhombic crystals; also granular, earthy. G. = 2·605. Color grayish white, pink, yellowish. Optically −. Found coating cerite at Bastnäs, Sweden; with zinc ores of the Saucon valley, Lehigh Co., Pa.; at the Sandford iron-ore bed, Moriah, N. Y.

TRONA. Urao.

Monoclinic. Axes $a : b : c = 2{\cdot}8460 : 1 : 2{\cdot}9700$; $\beta = 77° 23'$.

ca, 001 ∧ 100 = 77° 23′.
co, 001 ∧ $\bar{1}11$ = 75° 53½′.
oo″, $\bar{1}11$ ∧ $11\bar{1}$ = 47° 35½′.

768



Often fibrous or columnar massive.

Cleavage: *a* (100) perfect; *o* ($\bar{1}11$); *c* (001) in traces. Fracture uneven to subconchoidal. H. = 2·5–3. G. = 2·11–2·14. Luster vitreous, glistening. Color gray or yellowish white. Translucent. Taste alkaline. Optically −. Index, 1·507.

Comp. — $Na_2CO_3.HNaCO_3.2H_2O$ or $3Na_2O.4CO_2.5H_2O$ = Carbon dioxide 38·9, soda 41·2, water 19·9 = 100.

Chatard established the above composition for urao, and showed that trona, sometimes called "sesquicarbonate of soda," is an impure form of the same compound.

Pyr., etc. — In the closed tube yields water and carbon dioxide. B.B. imparts an intensely yellow color to the flame. Soluble in water, and effervesces with acids. Reacts alkaline with moistened test-paper.

Obs. — Found in the province of Fezzan, Africa, forming thin superficial crusts; Natroun lakes, Egypt; from Vesuvius; at the bottom of a lake at Lagunilla, Venezuela. Efflorescences of trona occur near the Sweetwater river, Rocky Mountains. An extensive bed in Churchill Co., Nev. In fine crystals at Borax lake, San Bernardino Co., Cal., with hanksite, glauberite, thenardite, etc.

Hydromagnesite. Basic magnesium carbonate, $3MgCO_3.Mg(OH)_2.3H_2O$. Crystals small, tufted. Also amorphous; as chalky crusts. Color and streak white. Index, 1·530. Often occurs with serpentine; thus at Hrubschütz, in Moravia; at Kraubat, Styria, etc. Also similarly near Texas, Pa.; Hoboken, N. J. Material closely similar from saline crusts on lava at Alpharoëssa, Santorin Island, has been called *giorgiosite*.

Hydrogiobertite. $MgCO_3.Mg(OH)_2.2H_2O$. In light gray spherical forms. From the neighborhood of Pollena, Italy. Deposited from Phillips Springs, Napa Co., Cal.

Artinite. $MgCO_3.Mg(OH)_2.3H_2O$. Orthorhombic. Radiating fibrous. H. = 2·0. G. = 2·0. White. $\beta = 1{\cdot}54$. From Val Laterna and Emarede, Val Aosta, Piedmont, Italy.

Lansfordite. $3MgCO_3.Mg(OH)_2.21H_2O$. Biaxial −. Indices, 1·42–1·503. Occurs as small stalactites in the anthracite mine at Nesquehoning near Lansford, Schuylkill Co., Pa.; changed on exposure to nesquehonite.

Brugnatellite. $MgCO_3.5Mg(OH)_2.Fe(OH)_3.4H_2O$. Micaceous, lamellar. Perfect cleavage. Color flesh-pink. $\omega = 1{\cdot}53$. Found in an old asbestos mine at Torre Santa Maria, Val Malenco, Lombardy, Italy.

GAJITE. A basic hydrous calcium, magnesium carbonate. Rhombohedral cleavage. Granular structure. H. = 3·5. G. = 2·62. Color, white. Strong birefringence. Found near Pleŝce, in the district Gorskikotar, Croatia.

Stichtite. $2MgCO_3.5Mg(OH)_2.2Cr(OH)_3$. Micaceous. In scales. G. = 2·16. Color lilac. Optically uniaxial or feebly biaxial. Optically −. Index, 1·54. An alteration product of *serpentine* from Dundas, Tasmania.

Zaratite. Emerald Nickel. $NiCO_3.2Ni(OH)_2.4H_2O$. In mammillary incrustations; also massive, compact. Color emerald-green. Occurs on chromite at Texas, Lancaster Co., Pa.; at Swinaness, Unst, Shetland; Igdlokunguak, Greenland.

Remingtonite. A hydrous cobalt carbonate. A rose-colored incrustation, soft and earthy. From a copper mine near Finksburg, Carroll Co., Md.; Boleo, Lower California.

Tengerite. A supposed yttrium carbonate. In white pulverulent coatings. On gadolinite at Ytterby, Sweden. A similar mineral is associated with the gadolinite of Llano Co., Tex.

Bismutite. A basic bismuth carbonate, perhaps $Bi_2O_3.CO_2.H_2O$. Incrusting, or earthy and pulverulent; amorphous. G. = 6·86–6·9 Breith.; 7·67 Rg. Color white, green, yellow and gray. Index, 2·25. Occurs in Germany, at Schneeberg and Johanngeorgenstadt, with native bismuth, and at Joachimstal, Bohemia. In the United States, in S. C., at Brewer's mine; in Gaston Co., N. C.

Uranothallite. $2CaCO_3.U(CO_3)_2.10H_2O$. In scaly or granular crystalline aggregates. Color siskin-green. Occurs on uraninite at Joachimstal, Bohemia.

Liebigite. A hydrous carbonate of uranium and calcium. In mammillary concretions, or thin coatings. Color apple-green. Occurs on uraninite near Adrianople, Turkey; also Johanngeorgenstadt, Germany, and Joachimstal, Bohemia.

Voglite. A hydrous carbonate of uranium, calcium and copper. In aggregations of crystalline scales. Color emerald-green to bright grass-green. From the Elias mine, near Joachimstal, on uraninite, Bohemia.

Oxygen Salts

2. SILICATES

The Silicates are in part strictly anhydrous, in part hydrous, as the zeolites and the amorphous clays, etc. Furthermore, a large number of the silicates yield more or less water upon ignition, and in many cases it is known that they are, therefore, to be regarded as basic (or acid) silicates. The line, however, between the strictly anhydrous and hydrous silicates cannot be sharply drawn, since with many species which yield water upon ignition the part played by the elements forming the water is as yet uncertain. Furthermore, in the cases of several groups, the strict arrangement must be deviated from, since the relation of the species is best exhibited by introducing the related hydrous species immediately after the others.

This chapter closes with a section including the Titanates, Silico-titanates, Titano-niobates, etc., which connect the Silicates with the Niobates and Tantalates. Some Titanates have already been included among the Oxides.

Section A. Chiefly Anhydrous Silicates

I. Disilicates, Polysilicates
II. Metasilicates
III. Orthosilicates
IV. Subsilicates

The Disilicates, RSi_2O_5, are salts of disilicic acid, $H_2Si_2O_5$, and have an oxygen ratio of silicon to bases of 4 : 1, as seen when the formula is written after the dualistic method, $RO.2SiO_2$.

The Polysilicates, $R_2Si_3O_8$, are salts of polysilicic acid, $H_4Si_3O_8$, and have an oxygen ratio of 3 : 1, as seen in $2RO.3SiO_2$.

The Metasilicates, $RSiO_3$, are salts of metasilicic acid, H_2SiO_3, and have an oxygen ratio of 2 : 1. They have hence been called *bisilicates*.

The Orthosilicates, R_2SiO_4, are salts of orthosilicic acid, H_4SiO_4, and have an oxygen ratio of 1 : 1. They have hence been called *unisilicates*. The majority of the silicates fall into one of the last two groups.

Furthermore, there are a number of species characterized by an oxygen ratio of less than 1 : 1, *e.g.*, 3 : 4, 2 : 3, etc. These basic species are grouped as SUBSILICATES. Their true position is often in doubt; in most cases they are probably to be regarded as basic salts belonging to one of the other groups.

The above classification cannot, however, be carried through strictly, since there are many species which do not exactly conform to any one of the groups named, and often the true interpretation of the composition is doubtful. Furthermore, within the limits of a single group of species, connected closely in all essential characters, there may be a wide variation in the proportion of the acidic element. Thus the triclinic feldspars, placed among the polysilicates, range from the true polysilicate, $NaAlSi_3O_8$, to the orthosilicate, $CaAl_2Si_2O_8$, with many intermediate compounds, regarded as isomorphous mixtures of these extremes. Similarly of the scapolite group, which, however, is included among the orthosilicates, since the majority of the compounds observed approximate to that type. The micas form another example.

I. Disilicates, RSi_2O_5. Polysilicates, $R_2Si_3O_8$

PETALITE.

Monoclinic. Crystals rare (*castorite*). Usually massive, foliated cleavable (*petalite*).

Cleavage: *c* (001) perfect; *o* (201) easy; *z* ($\bar{9}05$) difficult and imperfect. Fracture imperfectly conchoidal. Brittle. H. = 6–6·5. G. = 2·39–2·46. Luster vitreous, on *c* (001) pearly. Colorless, white, gray, occasionally reddish or greenish white. Streak uncolored. Transparent to translucent. $\alpha = 1·504$. $\beta = 1·510$. $\gamma = 1·516$.

Comp. — $LiAl(Si_2O_5)_2$ or $Li_2O.Al_2O_3.8SiO_2$ = Silica 78·4, alumina 16·7, lithia, 4·9 = 100.

Pyr., etc. — Gently heated emits a blue phosphorescent light. B.B. fuses quietly at 4 and gives the reaction for lithia. With borax it forms a clear, colorless glass. Not acted on by acids.

Obs. — Petalite occurs at the iron mine of Utö, Sweden, with lepidolite, tourmaline, spodumene, and quartz; on Elba (*castorite*). In the United States, at Bolton, Mass., with scapolite; at Peru, Me., with spodumene in albite. The name *petalite* is from *πέταλον, a leaf*, alluding to the cleavage.

Milarite. $HKCa_2Al_2(Si_2O_5)_6$. In hexagonal prisms. H. = 5·5–6. G. = 2·55–2·59. Colorless to pale green, glassy. From Val Giuf, Grisons, Switzerland.

Eudidymite. $HNaBeSi_3O_8$. Monoclinic. In white, glassy, twinned crystals, tabular in habit. H. = 6. G. = 2·553. Optically +. Indices, 1·545–1·551. Occurs very sparingly in elæolite-syenite on the island Ovre-Arö, in the Langesundfiord, Norway; from Narsarsuk, Greenland.

Epididymite. Same composition as eudidymite. Orthorhombic. Tabular ‖ *c* (001). Cleavage, *b*(010) and *c*(001), perfect. H. = 5·5. G. = 3·55. Optically −. Indices, 1·565–1·569. Narsarsuk, Greenland.

RIVAITE. $(Ca,Na_2)Si_2O_5$. Monoclinic? In fibrous aggregates. H. = 5. G. = 2·55. Color, pale lavender to dark blue. Fibers show parallel extinction with positive elongation. Easily fusible. Insoluble in hydrochloric acid. Found in loose nodules on Vesuvius.

Feldspar Group

α. Monoclinic Section

		$a : b : c$	β'
Orthoclase	$KAlSi_3O_8$	0·6585 : 1 : 0·5554	116° 3′
Soda-Orthoclase	$(K,Na)AlSi_3O_8$ $(Na,K)AlSi_3O_8$		
Hyalophane	$(K_2,Ba)Al_2Si_4O_{12}$	0·6584 : 1 : 0·5512	115° 35′
Celsian	$BaAl_2Si_2O_8$	0·657 : 1 : 0·554	115° 2′

β. Triclinic Section

Microcline	$KAlSi_3O_8$
Soda-microcline	$(K,Na)AlSi_3O_8$
Anorthoclase	$(Na,K)AlSi_3O_8$

Albite-anorthite Series. *Plagioclase Feldspars*

		$a : b : c$	α	β	γ
Albite	$NaAlSi_3O_8$	0·6335 : 1 : 0·5577	94° 3′	116° 29′	88° 9′
Oligoclase	$\begin{pmatrix} nNaAlSi_3O_8 \\ mCaAl_2Si_2O_8 \end{pmatrix}$	0·6321 : 1 : 0·5524	93° 4′	116° 23′	90° 5′
Andesine		0·6357 : 1 : 0·5521	93° 23′	116° 29′	89° 59′
Labradorite		0·6377 : 1 : 0·5547	93° 31′	116° 3′	89° 54½′
Anorthite	$CaAl_2Si_2O_8$	0·6347 : 1 : 0·5501	93° 13′	115° 55′	91° 12′

The general characters of the species belonging in the FELDSPAR GROUP are as follows:

1, *Crystallization* in the monoclinic or triclinic systems, the crystals of the different species resembling each other closely in angle, in general habit, and in methods of twinning. The prismatic angle in all cases differs but a few degrees from 60° and 120°.

2, *Cleavage* in two similar directions parallel to the base c (001) and clinopinacoid (or brachypinacoid) b (010), inclined at an angle of 90° or nearly 90°. 3, *Hardness* between 6 and 6·5. 4, *Specific Gravity* varying between 2·5 and 2·9, and mostly between 2·55 and 2·75. 5, *Color* white or pale shades of yellow, red or green, less commonly dark. 6, In composition silicates of aluminium with either potassium, sodium, or calcium, and rarely barium, while magnesium and iron are always absent. Furthermore, besides the several distinct species there are many intermediate compounds having a certain independence of character and yet connected with each other by insensible gradations; all the members of the series showing a close relationship not only in composition but also in crystalline form and optical characters.

The species of the Feldspar Group are classified, first as regards form, and second with reference to composition. The *monoclinic* species include (see above): ORTHOCLASE, potassium feldspar, and SODA-ORTHOCLASE, potassium-sodium feldspar; also HYALOPHANE and CELSIAN, barium feldspars.

The *triclinic* species include: MICROCLINE and ANORTHOCLASE, potassium-sodium feldspars; ALBITE, sodium feldspar; ANORTHITE, calcium feldspar.

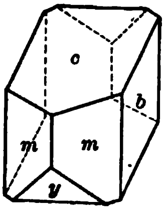
Also intermediate between albite and anorthite the isomorphous subspecies, sodium-calcium or calcium-sodium feldspars: OLIGOCLASE, ANDESINE, LABRADORITE.

α. Monoclinic Section

ORTHOCLASE.

Monoclinic. Axes $a : b : c = 0{\cdot}6585 : 1 : 0{\cdot}5554$; $\beta = 63° 57'$.

767



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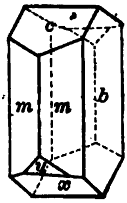

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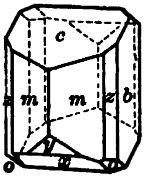

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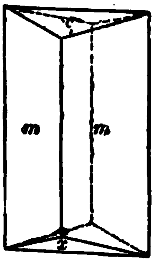
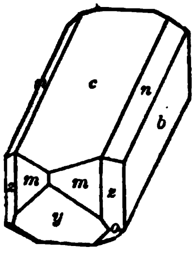


mm''', 110 ∧ $1\bar{1}0$ = 61° 13′.
zz', 130 ∧ $\bar{1}30$ = 58° 48′.
cx, 001 ∧ $\bar{1}01$ = 50° 16½′.
cy, 001 ∧ $\bar{2}01$ = 80° 18′.

cn, 001 ∧ 021 = 44° 56½′.
nn', 021 ∧ $0\bar{2}1$ = 89° 53′.
cm, 001 ∧ 110 = 67° 47′.
co, 001 ∧ $\bar{1}11$ = 55° 14½′.

Twins: tw. pl. (1) *a* (100), or tw. axis *c*, the common *Carlsbad* twins, either of irregular penetration (Fig. 772) or contact type; the latter usually with *b* (010) as composition-face, often then (Fig. 773) with *c* (001) and *x* ($\bar{1}$01) nearly in a plane, but to be distinguished by luster, cleavage, etc. (2) *n* (021), the *Baveno* twins forming nearly square prisms (Fig. 774), since *cn* = 44° 56½′, and hence $c\underline{c}$ = 89° 53′; often repeated as fourlings (Fig. 447, p. 171), also in square prisms, elongated || *a* axis. (3) *c* (001), the *Manebach* twins (Fig. 775), usually contact-twins with *c* as comp.-face. Also other rarer laws.

771



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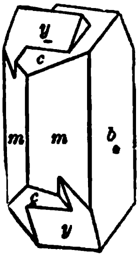

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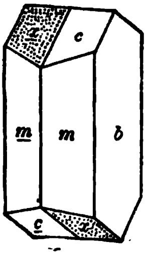

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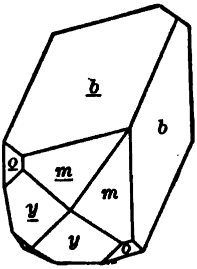

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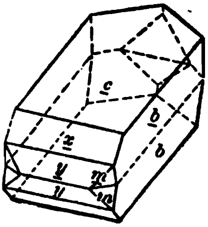
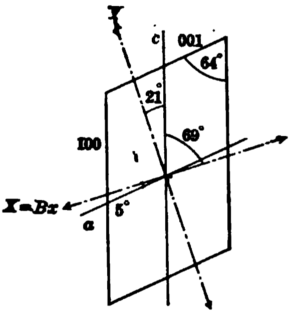


Crystals often prismatic || *c* axis; sometimes orthorhombic in aspect (Fig. 770) since *c* (001) and *x* ($\bar{1}$01) are inclined at nearly equal angles to the vertical axis; also elongated || *a* axis (Fig. 771) with *b* (010) and *c* (001) nearly equally developed; also thin tabular || *b* (010): rarely tabular || *a* (100), a face not often observed. Often massive, coarsely cleavable to granular; sometimes lamellar. Also compact crypto-crystalline, and flint-like or jasper-like.

Cleavage: *c* (001) perfect; *b* (010) somewhat less so; prismatic *m* (110) imperfect, but usually more distinct parallel to one prismatic face than to the other. Parting sometimes distinct parallel to *a* (100), also to a hemi-orthodome, inclined a few degrees to the orthopinacoid; this may produce a satin-like luster or schiller (p. 251), the latter also often present when the parting is not distinct. Fracture conchoidal to uneven. Brittle. H. = 6. G. = 2·57. Luster vitreous; on *c* (001) often pearly. Colorless, white, pale yellow and flesh-red common, gray; rarely green. Streak uncolored.

Optically negative in all cases (Fig. 776). Ax. pl. usually ⊥ *b* (010), sometimes || *b*, also changing from the former to the latter on increase of temperature (see p. 297). For *adularia* $Bx_{a.r} \wedge c$ axis = $-69° 11'$, $Bx_{a.bl} \wedge c$ axis = $-69° 37'$. Hence Bx_a and the extinction-direction (Fig. 776) inclined a few degrees only to *a* axis, or the edge *b*/*c*; thus +3° to +7° usually, or up to +10° or +12° in varieties rich in Na_2O. Dispersion $\rho > v$; also horizontal, strongly marked, or inclined, according to position of ax. pl. Axial angles variable. Birefringence low, $\gamma - \alpha = 0·007 - 0·005$. For adularia

776



$$\alpha_y = 1·5190, \quad \beta_y = 1·5237, \quad \gamma_y = 1·5260.$$
$$\therefore 2V_y = 69° 43', \quad 2E_y = 121° 6'.$$

Comp. — A silicate of aluminium and potassium, $KAlSi_3O_8$ or $K_2O.Al_2O_3.6SiO_2$ = Silica 64·7, alumina 18·4, potash 16·9 = 100. Sodium is often also present, replacing part of the potassium, and sometimes exceeds it in amount; these varieties are embraced under the name soda-orthoclase (the name *barbierite* has been proposed for this material whose existence, as a distinct though rare mineral, seems to have been proven).

Var. — The prominent varieties depend upon crystalline habit and method of occurrence more than upon difference of composition.

1. *Adularia.* The pure or nearly pure potassium silicate. Usually in crystals, like Fig. 770 in habit; often with vicinal planes; Baveno twins common. G. = 2·565. Transparent or nearly so. Often with a pearly opalescent reflection or schiller or a delicate play of colors; some *moonstone* is here included, but the remainder belongs to albite or other of the triclinic feldspars. The original adularia (Adular) is from the St. Gothard region in Switzerland. *Valencianite,* from the silver mine of Valencia, Mexico, is adularia.

2. *Sanidine* or *glassy feldspar.* Occurs in crystals, often transparent and glassy, embedded in rhyolite, trachyte (as of the Siebengebirge, Germany), phonolite, etc. Habit often tabular || *b* (010) (hence named from σανίς, a *tablet,* or *board*); also in square prisms (*b*, *c*); Carlsbad twins common. Most varieties contain sodium as a prominent constituent, and hence belong to the soda-orthoclase. Natronsanidine is a sanidine-like soda-orthoclase from a soda liparite from Mitrowitza, Servia.

Rhyacolite. Occurs in glassy crystals at Monte Somma, Vesuvius; named from ῥύαξ, *stream* (lava stream).

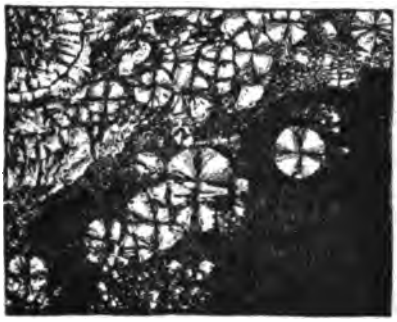
3. *Isothose* is said to be a variety having a different optical orientation than normal orthoclase.

4. *Ordinary.* In crystals, Carlsbad and other twins common; also massive or cleavable, varying in color from white to pale yellow, red or green, translucent; sometimes aventurine. Here belongs the common feldspar of granitoid rocks or granite veins. Usually contains a greater or less percentage of soda (soda-orthoclase). Compact cryptocrystalline orthoclase makes up the mass of much felsite, but to a greater or less degree admixed with quartz; of various colors, from white and brown to deep red. Much of what has been called orthoclase, or common potash feldspar, has proved to belong to the related triclinic species, microcline. Cf. p. 461 on the relations of the two species. Chesterlite and Amazon stone are microcline; also most aventurine orthoclase. *Loxoclase* contains sodium in considerable amount (7·6 Na_2O); from Hammond, St. Lawrence Co., N. Y. *Murchisonite* is a flesh-red feldspar similar to perthite (p. 460), with gold-yellow reflections in a direction ⊥ *b* (010) and nearly parallel to $\bar{7}01$ or $\bar{8}01$ (p. 457); from Dawlish and Exeter, England.

The spherulities noted in some volcanic rocks, as in the rhyolite of Obsidian Cliff in the Yellowstone Park, are believed to consist essentially of orthoclase needles with quartz.

These are shown in Figs. 777 and 778 (from Iddings; much magnified) as they appear in polarized light (crossed nicols).

777



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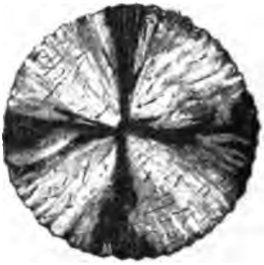


Pyr., etc. — B.B. fuses at 5; varieties containing much soda are more fusible. Loxoclase fuses at 4. Not acted upon by acids. Mixed with powdered gypsum and heated B. B. gives violet potassium flame visible through blue glass.

Diff. — Characterized by its crystalline form and the two cleavages at right angles to each other; harder than barite and calcite; not attacked by acids; difficultly fusible. Massive corundum is much harder and has a higher specific gravity.

Micro. — Distinguished in rock sections by its low refraction (low relief) and low interference-colors, which last scarcely rise to white of the first order — hence lower than those of quartz; also by its biaxial character in convergent light and by the distinct cleavages. It is colorless in ordinary light and may be limpid, but is frequently turbid and brownish from the presence of very minute scales of kaolin due to alteration from weathering; this change is especially common in the older granular rocks, as granite and gneiss.

Artif. — Orthoclase has not been produced artificially by the methods of dry fusion. It can, however, be crystallized from a dry melt when certain other substances, like tungstic acid, alkaline phosphates, etc., are added. The function of these additions in the reactions is not clear. Orthoclase is more easily formed by hydrochemical methods. It has been produced by heating gelatinous silica, alumina, caustic potash and water in a sealed tube. Orthoclase has also been formed by heating potassium silicate and water together with muscovite.

Obs. — Orthoclase in its several varieties belongs especially to the crystalline rocks, occurring as an essential constituent of granite, gneiss, syenite, also porphyry, further (var., *sanidine*) trachyte, phonolite, etc. In the massive granitoid rocks it is seldom in distinct, well-formed, separable crystals, except in veins and cavities; such crystals are more common, however, in volcanic rocks like trachyte.

Adularia occurs in the crystalline rocks of the central and eastern Alps, associated with smoky quartz and albite, also titanite, apatite, etc.; the crystals are often coated with chlorite; also on Elba. Fine crystals of orthoclase, often twins, are obtained from Baveno, Lago Maggiore, Italy; the Fleimstal, Tyrol, Austria, a red variety; Bodenmais, Carlsbad, and Elbogen in Bohemia; Striegau, etc., in Silesia. Also Arendal in Norway, and near Shaitansk in the Ural Mts.; Land's End and St. Agnes in Cornwall; the Mourne Mts., Ireland, with beryl and topaz. From Tamagama Yama, Japan, with topaz and smoky quartz. *Moonstone* is brought from Ceylon. Crystals of gem quality from Itrongahy, Madagascar. *Valencianite* from Guanajuato, Mexico. Crystals from Eganville, Ontario.

In the United States, orthoclase is common in the crystalline rocks of New England, also of States south, further Colorado, California, etc. Thus at the Paris tourmaline locality, Me. In N. H., at Acworth. In Mass., at South Royalston and Barre. In Conn., at Haddam and Middletown, in large coarse crystals. In N. Y., in St. Lawrence Co., at Rossie; at Hammond (*loxoclase*); in Lewis Co., in white limestone near Natural Bridge; at Amity and Edenville. In Pa., in crystals at Leiperville, Mineral Hill, Delaware Co.; sunstone in Kennett Township. In N. C., at Washington Mine, Davidson Co. In Col., at the summit of Mt. Antero, Chaffee Co., in fine crystals, often twins; at Gunnison; Black

Hawk; Kokomo, Summit Co., Robinson, also at other points. Also similarly in Nev. and Cal. Large twin crystals from Barringer Hill, Llano Co., Texas.

Alter. — Orthoclase is frequently altered, especially through the action of carbonated or alkaline waters; the final result is often the removal of the potash and the formation of kaolin. Steatite, talc, chlorite, leucite, mica, laumontite, occur as pseudomorphs after orthoclase; and cassiterite and calcite often replace these feldspars by some process of solution and substitution.

Use. — In the manufacture of porcelain, both in the body of the ware and in the glaze on its surface.

PERTHITE. As first described, a flesh-red aventurine feldspar from Perth, Ontario, Canada, called a soda-orthoclase, but shown by Gerhard to consist of interlaminated orthoclase and albite. Many similar occurrences have since been noted, as also those in which microcline and albite are similarly interlaminated, the latter called *microcline-perthite*, or microcline-albite-perthite; this is true in part of the original perthite. When the structure is discernible only with the help of the microscope it is called *microperthite*. Brögger has investigated not only the microperthites of Norway, but also other feldspars characterized by a marked schiller; he assumes the existence of an extremely fine interlamination of albite and orthoclase || $\bar{8}01$, not discernible by the microscope (cryptoperthite), and connected with secondary planes of parting || 100 or || $\bar{8}01$, which is probably to be explained as due to incipient alteration.

Hyalophane. $(K_2,Ba)Al_2(SiO_3)_4$ or $K_2O.BaO.2Al_2O_3.8SiO_2$. Silica 51·6, alumina 21·9, baryta 16·4, potash 10·1 = 100. In crystals, like adularia in habit (Fig. 770, p. 457); also massive. Cleavage: *c* (001) perfect; *b* (010) somewhat less so. H. = 6–6·5. G. = 2·805. Optically —. α = 1·542. β = 1·545. γ = 1·547. Occurs in a granular dolomite in the Binnental, Switzerland; also at the manganese mine of Jakobsberg, Sweden. Some other feldspars containing 7 to 15 p. c. BaO have been described.

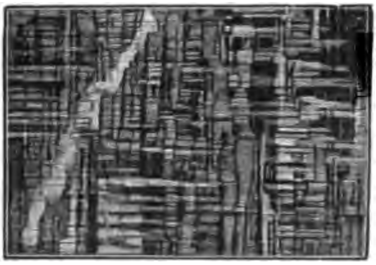
Celsian. $BaAl_2Si_2O_8$, similar in composition to anorthite, but containing barium instead of calcium. Monoclinic. In crystals showing a number of forms; twinned according to Carlsbad, Manebach and Baveno laws. Usually cleavable massive. H. = 6–6·5. G. = 3·37. Extinction on *b* (010) = 28° 3′. Colorless. Optically +. α = 1·584. β = 1·589. γ = 1·594. From Jakobsberg, Sweden. Name *baryta-orthoclase* given to mixtures of celsian and orthoclase. *Paracelsian* from Candoglia, Piedmont, Italy, is the same species.

β. Triclinic Section

MICROCLINE.

Triclinic. Near orthoclase in angles and habit, but the angle *bc* (010 ∧ 001) = about 89° 30′. Twins: like orthoclase, also polysynthetic twinning according to the albite and pericline laws (p. 464), common, producing two series of fine lamellæ nearly at right angles to each other, hence the characteristic grating-structure of a basal section in polarized light (Fig. 779). Also massive cleavable to granular compact.

779



Cleavage: *c* (001) perfect; *b* (010) somewhat less so; *M* (1$\bar{1}$0) sometimes distinct; *m* (110) also sometimes distinct, but less easy. Fracture uneven. Brittle. H. = 6–6·5. G. = 2·54–2·57. Luster vitreous, on *c* (001) sometimes pearly. Color white to pale cream-yellow, also red, green. Transparent to translucent. Optically —. Ax. pl. nearly perpendicular (82°–83°) to *b* (010). Bx_0 inclined 15° 26′ to a normal to *b* (010). Dispersion $\rho < v$ about Bx_0. Extinction-angle on *c* (001), +15° 30′; on *b* (010), +5° to 6° (Fig. 784, p. 462). Optically —. α = 1·522. β = 1·526. γ = 1·530. 2 V = 83°.

The essential identity of orthoclase and microcline has been urged by Mallard and Michel-Lévy on the ground that the properties of the former would belong to an aggregate of submicroscopic twinning lamellæ of the latter, according to the albite and pericline laws.

Comp. — Like orthoclase, $KAlSi_3O_8$ or $K_2O.Al_2O_3.6SiO_2$ = Silica 64·7, alumina 18·4, potash 16·9 = 100. Sodium is usually present in small amount: sometimes prominent, as in soda-microcline.

Pyr. — As for orthoclase.

Diff. — Resembles orthoclase but distinguished by optical characters (*e.g.*, the grating structure in polarized light, Fig. 779); also often shows fine twinning-striations on a basal surface (albite law).

Micro. — In thin sections like orthoclase but usually to be distinguished by the grating-like structure in polarized light due to triclinic twinning.

Obs. — Occurs under the same conditions as much common orthoclase. The beautiful *amazonstone* from the Ural Mts., also that occurring in fine groups of large crystals of deep color in the granite of Pike's Peak, Col., is microcline. Crystals from Ivigtut, Greenland. From Antsongombato and Antoboko (amazonstone), Madagascar. *Chesterlite* from Poorhouse quarry, Chester Co., Pa., and the aventurine feldspar of Mineral Hill, Pa., belong here. A pure variety occurs at Magnet Cove, Ark. Ordinary microcline is common at many points.

Use. — Same as for orthoclase; sometimes as an ornamental material (amazonstone).

Anorthoclase. Soda-microcline. A triclinic feldspar with a cleavage-angle, *bc*, 010 $\wedge$ 001, varying but little from 90°. Form like that of the ordinary feldspars. Twinning as with orthoclase; also polysynthetic according to the albite and pericline laws; but in many cases the twinning laminæ very narrow and hence not distinct. Rhombic section (see p. 462) inclined on *b* (010) 4° to 6° to edge *b*/*c*. G. = 2·57–2·60. Cleavage, hardness, luster, and color as with other members of the group. Optically −. Extinction-angle on *c* (001) +5° 45′ to + 2°; on *b* (010) 6° to 9.8°. Bx_a nearly $\perp$ $\mathfrak{y}$ ($\bar{2}01$). Dispersion $\rho > v$; horizontal distinct. $\alpha = 1·523$. $\beta = 1·529$. $\gamma = 1·531$. Axial angle variable with temperature, becoming in part monoclinic in optical symmetry between 86° and 264° C., but again triclinic on cooling; this is true of those containing little calcium.

Chiefly a soda-potash, feldspar $NaAlSi_3O_8$ and $KAlSi_3O_8$, the sodium silicate usually in larger proportion (2 : 1, 3 : 1, etc.), as if consisting of albite and orthoclase molecules. Calcium ($CaAl_2Si_2O_8$) is also present in relatively very small amount.

These triclinic soda-potash feldspars are chiefly known from the andesitic lavas of Pantelleria. Most of these feldspars come from a rock, called pantellerite. Also prominent from the augite-syenite of southern Norway and from the "Rhomben-porphyr" near Christiania. Here is referred also a feldspar in crystals, tabular ‖ *c* (001), and twinned according to the Manebach and less often Baveno laws occurring in the lithophyses of the rhyolite of Obsidian Cliff, Yellowstone Park. It shows the blue opalescence in a direction parallel with a steep orthodome (cf. p. 457).

Albite-Anorthite Series. *Plagioclase Feldspars* *

Between the isomorphous species

ALBITE	$NaAlSi_3O_8$	Ab
ANORTHITE	$CaAl_2Si_2O_8$	An

there are a number of intermediate subspecies, regarded, as urged by Tschermak, as isomorphous mixtures of these molecules, and defined according to the ratio in which they enter; their composition is expressed in general by the formula Ab_nAn_m. They are:

OLIGOCLASE	Ab_6An_1	to	Ab_3An_1
ANDESINE	Ab_3An_1	to	Ab_1An_1
LABRADORITE	Ab_1An_1	to	Ab_1An_3
and Bytownite	Ab_1An_3	to	Ab_1An_6

From albite through the successive intermediate compounds to anorthite with the progressive change in composition (also specific gravity, melting points, etc.), there is also a corresponding change in crystallographic form, and in certain fundamental optical properties.

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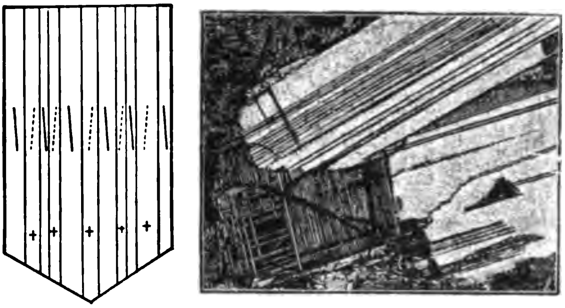
* The triclinic feldspars of this series, in which the two cleavages *b* (010) and *c* (001) are oblique to each other, are often called in general *plagioclase* (from πλάγιος, *oblique*).

Crystalline Form. The axial ratios and angles given on p. 456 show that these triclinic feldspars approach orthoclase closely in form, the most obvious difference being in the cleavage-angle *bc* 010 ∧ 001, which is 90° in orthoclase, 86° 24′ in albite, and 85° 50′ in anorthite. There is also a change in the axial angle γ, which is 88° in albite, about 90° in oligoclase and andesine, and 91° in anorthite. This transition appears still more strikingly in the position of the "rhombic section," by which the twins according to the pericline law are united as explained below.

780 781



Plagioclase with twinning lamellæ. Fig. 780 section ∥ *c* (001) showing vibration-directions (cf. Fig. 784), ordinary light; Fig. 781 section in polarized light.

Twinning. The plagioclase feldspars are often twinned in accordance with the Carlsbad, Baveno, and Manebach laws common with orthoclase (p. 457). Twinning is also almost universal according to the *albite law* — twinning plane the brachypinacoid; this is usually polysynthetic, *i.e.*, repeated in the form of thin lamellæ, giving rise to fine striations on the basal cleavage surface (Figs. 780, 781). Twinning is also common according to the *pericline law* — twinning axis the macrodiagonal axis *b*; when polysynthetic this gives another series of fine striations seen on the brachypinacoid.

The composition-plane in this pericline twinning is a plane passing through the crystal in such a direction that its intersections with the prismatic faces and the brachypinacoid make equal plane angles with each other. The position of this rhombic section and the consequent direction of the striations on the brachypinacoid change rapidly with a small variation in the angle γ. In general it may be said to be approximately parallel to the base, but in albite it is inclined backward (+, Figs. 782 and 784) and in anorthite to the front (—, Fig. 783); for the intermediate species its position varies progressively with the composition.

782 783 784

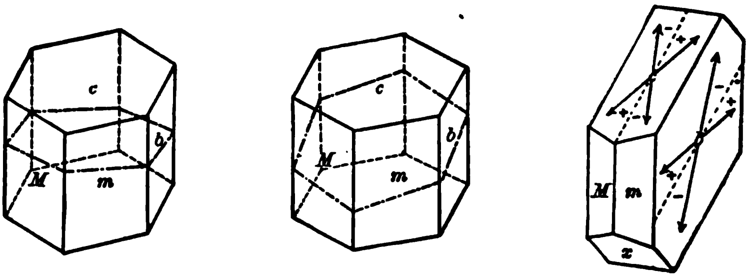
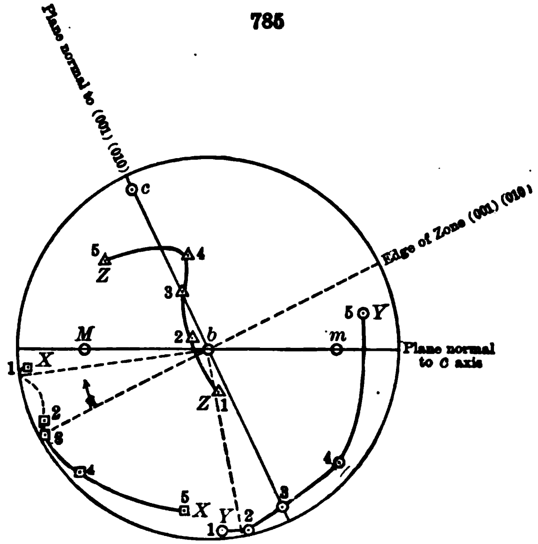


Fig. 782, Rhombic section in albite. 783, Same in anorthite. 784, Typical form showing + and — extinction-directions on *c* (001) and *b* (010).

Thus for the angle between the trace of this plane on the brachypinacoid and the edge *b/c*, we have for Albite +22° to +20°; for Oligoclase +9° to +3½°; for Andesine +1° to −2°; for Labradorite −9° to −10°; for Anorthite −15° to −17°.

If the composition-plane is at right angles or nearly so to the basal plane, as happens in the case of microcline, the polysynthetic lamellæ then show prominently in a basal section, together with those due to the albite twinning. Hence the grating structure characteristic of microline.

785

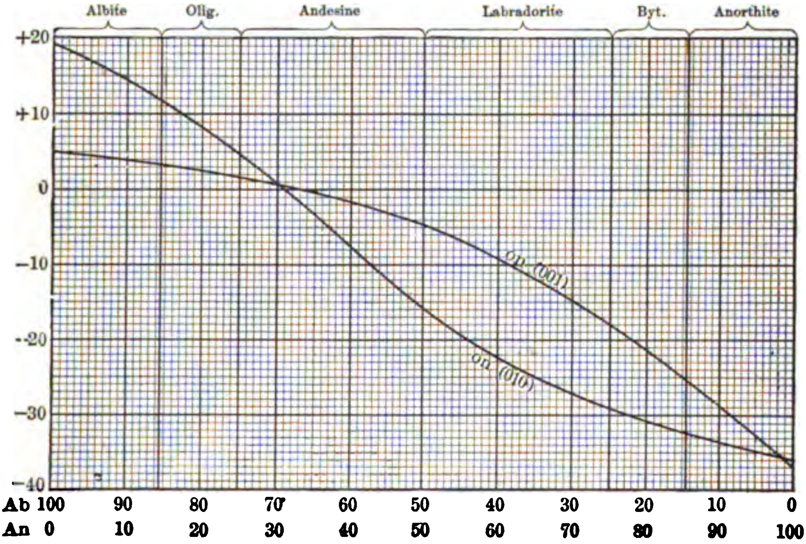


Projection of the optical directions X, Y and Z upon *b* (010). 1, Albite; 2, Oligoclase; 3, Andesine; 4, Labradorite; 5, Anorthite. (After Iddings.)

Optical Characters. There is also a progressive change in the position of the ether-axes and the optic axial plane in passing from albite to anorthite. This is most simply exhibited by the position of the planes of light-vibration, as observed in sections parallel to the two cleavages, basal *c* and brachy-pinacoidal *b*, in other words the extinction-angle formed on each face with the edge *b*/*c* (cf. Fig. 784).

The approximate position of the ether-axes for the different feldspars is shown in Fig. 785 (after Iddings). The axis *Z* does not vary very much from the zone *bc*, 010 ∧ 001, but the axis *X* varies widely, and hence the axial plane has an entirely different position in albite from what it has in anorthite. Furthermore albite is optically pos-

786



Extinction Angles on (001) and (010) in the Lime-soda feldspars. (After Iddings.)

itive, that is Z = Bx, while anorthite is negative or X = Bx; for certain andesines the axial angle is sensibly 90°.

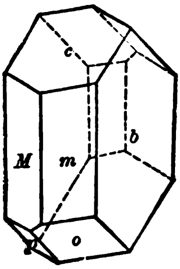
Fig. 786 (after Iddings) shows the variation in the extinction angles on the cleavage faces, *c* (001) and *b* (010), for the different mixtures of the albite and anorthite molecule.

Micro. — In rock sections the plagioclase feldspars are distinguished by their lack of color, low refractive relief, and low interference-colors, which in good sections are mainly dark gray and scarcely rise into white of the first order; also by their biaxial character in converging light. In the majority of cases they are easily told by the parallel bands or fine lamellæ which pass through them due to the multiple twinning according to the albite law; one set of bands or twin lamellæ exhibits in general a different interference-color from the other (cf. Figs. 780, 781). They are thus distinguished not only from quartz and orthoclase, with which they are often associated, but from all the common rock-making minerals. To distinguish the different species and sub-species from one another, as albite from laboradorite or andesine, is more difficult. In sections having a definite orientation (‖ *c* (001) and ‖ *b* (010)) this can generally be done by determining the extinction angles (cf. p. 462 and Fig. 784). In general in rock sections special methods are required; these are discussed in the various texts devoted to this subject.

ALBITE.

Triclinic. Axes $a : b : c = 0{\cdot}6335 : 1 : 0{\cdot}5577$; $\alpha = 94° 3'$, $\beta = 116° 29'$, $\gamma = 88° 9'$.

787



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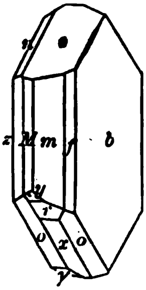
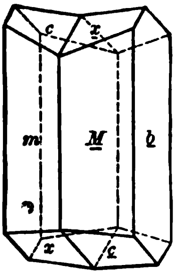


789



bc, $010 \wedge 001 = 86° 24'$.
mM, $110 \wedge 1\bar{1}0 = 59° 14'$.
bm, $010 \wedge 110 = 60° 26'$.
cm, $001 \wedge 110 = 65° 17'$.
cM, $001 \wedge 1\bar{1}0 = 69° 10'$.
cx, $001 \wedge \bar{1}01 = 52° 16'$.

Twins as with orthoclase; also very common, the tw. pl. *b* (010), *albite law* (p. 462), usually contact-twins, and polysynthetic, consisting of thin lamellæ and with consequent fine striations on *c*(001) (Fig. 790); tw. axis *b* axis, *pericline law*, contact-twins whose composition-face is the *rhombic section* (Figs. 782 and 792); often polysynthetic and showing fine striations which on *b* (010) are inclined backward +22° to the edge *b*/*c*.

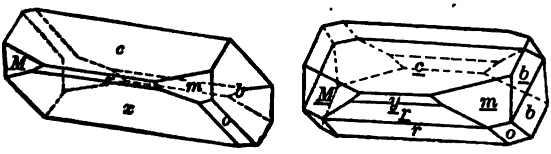
790

Crystals often tabular ‖ *b* (010); also elongated ‖ *b* axis as in the variety pericline. Also massive, either lamellar or granular; the laminæ often curved, sometimes divergent; granular varieties occasionally quite fine to impalpable.

Cleavage: *c*(001) perfect; *b*(010) somewhat less so; *m* (110) imperfect. Fracture uneven to conchoidal. Brittle. H. = 6–6·5. G. = 2·62–2·65. Luster vitreous; on a cleavage surface often pearly. Color white; also occasionally bluish, gray, reddish, greenish, and green; sometimes having a bluish opalescence or play of colors on *c* (001). Streak uncolored. Transparent to subtranslucent.

Optically +. Extinction-angle with edge $b/c = +4° 30'$ to 2° on c, and $= +20°$ to 15° on b (Fig. 782). Dispersion for Bx_a, $\rho < v$; also inclined, horizontal; for Bx_o, $\rho > v$; inclined, crossed. $\alpha = 1·531$. $\beta = 1·534$. $\gamma = 1·540$. $2V = 77°$. Birefringence weak, $\gamma - \alpha = 0·009$.

791 792



Pericline

Comp. — A silicate of aluminium and sodium, $NaAlSi_3O_8$ or $Na_2O.Al_2O_3.6SiO_2$ = Silica 68·7, alumina 19·5, soda 11·8 = 100. Calcium is usually present in small amount, as anorthite ($CaAl_2Si_2O_8$), and as this increases it graduates through oligoclase-albite to oligoclase (cf. p. 466). Potassium may also be present, and it is then connected with anorthoclase and microcline.

Var. — *Ordinary.* In crystals and massive. The crystals often tabular ‖ b (010). The massive forms are usually nearly pure white, and often show wavy or curved laminæ. *Peristerite* is a whitish adularia-like albite, slightly iridescent, named from *περιστερά, pigeon. Aventurine* and *moonstone* varieties also occur. *Pericline* from the chloritic schists of the Alps is in rather large opaque white crystals, with characteristic elongation in the direction of the b axis, as shown in Figs. 791 and 792, and commonly twinned with this as the twinning axis (pericline law).

Pyr., etc. — B.B. fuses at 4 to a colorless or white glass, imparting an intense yellow to the flame. Not acted upon by acids.

Diff. — Resembles barite in some forms, but is harder and of lower specific gravity; does not effervesce with acid (like calcite). Distinguished optically and by the common twinning striations on c (001) from orthoclase; from the other triclinic feldspars partially by specific gravity and better by optical means (see p. 463).

Artif. — Albite acts, in regard to its artificial formation, like orthoclase, which see.

Obs. — Albite is a constituent of many igneous rocks, especially those of alkaline type, as granite, elæolite-syenite, diorite, etc.; also in the corresponding feldspathic lavas. In *perthite* (p. 460) it is interlaminated with orthoclase or microcline, and similar aggregations, often on a microscopic scale, are common in many rocks. Albite is common also in gneiss, and sometimes in the crystalline schists. Veins of albitic granite are often repositories of the rarer minerals and of fine crystallizations of gems, including beryl, tourmaline, allanite, columbite, etc. It is found in disseminated crystals in granular limestone.

Some of the most prominent European localities are in cavities and veins in the granite or granitoid rocks of the Swiss and Austrian Alps, associated with adularia, smoky quartz, chlorite, titanite, apatite, and many rarer species: it is often implanted in parallel position upon the orthoclase. Thus in the Alps the St. Gothard region; Roc Tourné near Modane, Savoie; on Mt. Skopi (*pericline*); Tavetschtal; in Austria at Schmirn and Greiner, Tyrol; also Pfitsch, Rauris, the Zillertal, Krimml, Schneeberg in Passeir, Tyrol, in simple crystals. Also in Dauphiné, France, in similar association; Elba. Also Hirschberg in Silesia; Penig in Saxony; with topaz at Mursinka in the Ural Mts. and near Miask in the Ilmen Mts.; Cornwall, England; Mourne Mts. in Ireland. Fine crystals from Greenland.

In the United States, in Me., at Paris, with red and blue tourmalines, also at Topsham. In Mass., at Chesterfield, in lamellar masses (*cleavelandite*), slightly bluish, also fine granular. In N. H., at Acworth and Alstead. In Conn., at Haddam; at the Middletown feldspar quarries, at Branchville, in fine crystals and massive. In N. Y., at Moriah, Essex Co., of a greenish color; at Diana, Lewis Co., and Macomb, St. Laurence Co. In Pa., at Unionville, Chester Co. In Va., at the mica mines near Amelia Court-House in splendid crystallizations. In Col., in the Pike's Peak region with smoky quartz and amazonstone.

The name *albite* is derived from *albus*, white, in allusion to its common color.

Use. — Same as orthoclase but not so commonly employed; some varieties which show an opalescent play of colors when polished form the ornamental material known as *moonstone.*

Oligoclase.

Triclinic. Axes, see p. 456. *bc*, 010 ∧ 001 = 86° 32′. Twins observed according to the Carlsbad, albite, and pericline laws. Crystals not common. Usually massive, cleavable to compact.

Cleavage: *c* (001) perfect; *b* (010) somewhat less so. Fracture conchoidal to uneven. Brittle. H. = 6–6·5. G. = 2·65–2·67. Luster vitreous to somewhat pearly or waxy. Color usually whitish, with a faint tinge of grayish green, grayish white, reddish white, greenish, reddish; sometimes aventurine. Transparent, subtranslucent. Optical characters, see p. 463.

Comp. — Intermediate between albite and anorthite and corresponding to Ab_6An_1 to Ab_2An_1, but chiefly to Ab_3An_1, p. 461.

Var. — 1. *Ordinary.* In crystals or more commonly massive, cleavable. The varieties containing soda up to 10 p. c. are called *oligoclase-albite.* 2. *Aventurine oligoclase,* or *sunstone,* is of a grayish white to reddish gray color, usually the latter, with internal yellowish or reddish fire-like reflections proceeding from disseminated crystals of probably either hematite or göthite.

Pyr., etc. — B.B. fuses at 3·5 to a clear or enamel-like glass. Not materially acted upon by acids.

Diff. — See orthoclase (p. 459) and albite (p. 465); also pp. 456, 463.

Obs. — Occurs in porphyry, granite, syenite, and also in different effusive rocks, as andesite. It is sometimes associated with orthoclase in granite or other granite-like rock. Among its localities are Danviks-Zoll near Stockholm, Sweden; Pargas in Finland; Shaitansk, Ural Mts.; in syenite of the Vosges Mts., France; at Albula in Grisons, Switzerland; Marienbad, Bohemia; in France at Chalanches in Allemont, and Bourg d'Oisans, Dauphiné; as *sunstone* at Tvedestrand, Norway; at Hitterö, Norway; Lake Baikal, Siberia.

In the United States, at Fine and Macomb, St. Lawrence Co., N. Y., in good crystals; at Danbury, Conn., with orthoclase and danburite; Haddam, Conn.; at the emery mine, Chester, Mass., granular; at Unionville, Pa., with euphyllite and corundum; Mineral Hill, Delaware Co., Pa.; at Bakersville, N. C., in clear glassy masses, showing cleavage but no twinning. Named in 1826 by Breithaupt from ὀλιγος, *little*, and *κλάσις*, *fracture*.

Andesine.

Triclinic. Axes, see p. 456. *bc*, 010 ∧ 001 = 86° 14′. Twins as with albite. Crystals rare. Usually massive, cleavable or granular.

Cleavage: *c* (001) perfect; *b* (010) less so; also *M* (1$\bar{1}$0) sometimes observed. H. = 5–6. G. = 2·68–2·69. Color white, gray, greenish, yellowish, flesh-red. Luster subvitreous to pearly. Optical characters, see p. 463.

Comp. — Intermediate between albite and anorthite, corresponding to Ab : An in the ratio of 3 : 2, 4 : 3 to 1 : 1, see p. 461.

Pyr., etc. — Fuses in thin splinters before the blowpipe. Imperfectly soluble in acids.

Obs. — Observed in many granular and volcanic rocks; thus occurs in the Andes, at Marmato, Colombia, as an ingredient of the rock called *andesite;* in the porphyry of l'Esterel, Dept. du Var, France; in the syenite of Alsace in the Vosges Mts.; at Vapnefiord, Iceland; Bodenmais, Bavaria; Frankenstein, Silesia. Sanford, Me., with vesuvianite. Common in the igneous rocks of the Rocky Mts. Crystals from Sardinia and Greenland.

Labradorite. Labrador Feldspar.

Triclinic. Axes, see p. 456. Cleavage angle *bc* 010 ∧ 001 = 86° 4′. Forms and twinning similar to the other plagioclase species. Crystals often very thin tabular || *b* (010); and rhombic in outline bounded by *cy* or *cx* (Fig. 455, p. 172). Also massive, cleavable or granular; sometimes cryptocrystalline or hornstone-like.

Cleavage: *c* (001) perfect; *b* (010) less so; *M* (1$\bar{1}$0) sometimes distinct. H. = 5–6. G. = 2·70–2·72. Luster on *c* pearly, passing into vitreous; elsewhere vitreous or subresinous. Color gray, brown, or greenish; sometimes colorless and glassy; rarely porcelain-white; usually a beautiful change of colors in cleavable varieties, especially $\|$ b (010). Streak uncolored. Translucent to subtranslucent. Optical characters, see p. 463.

Play of colors a common character, but sometimes wanting as in some colorless crystals. Blue and green are the predominant colors; but yellow, fire-red, and pearl-gray also occur. Vogelsang regards the common blue color of labradorite as an interference-phenomenon due to its lamellar structure, while the golden or reddish schiller, with the other colors, is due to the presence of black acicular microlites and yellowish red microscopic lamellæ, or to the combined effect of these with the blue reflections. Schrauf has examined the inclusions, their position, etc., and given the names *microplakite* and *microphyllite* to two groups of them. (See references on p. 181.)

Comp. — Intermediate between albite and anorthite and corresponding chiefly to Ab : An in a ratio of from 1 : 1 to 1 : 3, p. 461.

The feldspars which lie between labradorite proper and anorthite have been embraced by Tschermak under the name *bytownite*. The original bytownite of Thomson was a greenish white feldspathic mineral found in a boulder near Bytown (now Ottawa) in Ontario, Canada.

Pyr., etc. — B.B. fuses at 3 to a colorless glass. Decomposed with difficulty by hydrochloric acid, generally leaving a portion of undecomposed mineral.

Diff. — The beautiful play of colors is a common but not universal character. Otherwise distinguished as are the other feldspars (pp. 459, 465).

Obs. — Labradorite is an essential constituent of various igneous rocks, especially of the basic kinds, and usually associated with some member of the pyroxene or amphibole groups. Thus with hypersthene in norite, with diallage in gabbro, with some form of pyroxene in diabase, basalt, dolerite, also andesite, tephrite, etc. Labradorite also occurs in other kinds of lava, and is sometimes found in them in glassy crystals, as in those of Etna, Vesuvius, at Kilauea, Hawaiian Islands.

The labradoritic massive rocks are most common among the formations of the Archæan era. Such are part of those of British America, northern New York, Pennsylvania, Arkansas; those of Greenland, Norway, Finland, Sweden, and probably of the Vosges Mts.

On the coast of Labrador, labradorite is associated with hornblende, hypersthene, and magnetite. It is met with in many places in Quebec. Occurs abundantly through the central Adirondack region in northern N. Y.; in the Wichita Mts., Ark.

Labradorite was first brought from the Isle of Paul, on the coast of Labrador, by Mr. Wolfe, a Moravian missionary, about the year 1770.

Use. — The varieties showing a play of colors are used as ornamental material.

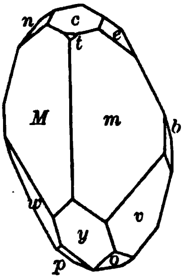
MASKELYNITE. In colorless isotropic grains in meteorites; composition near labradorite.

ANORTHITE. Indianite.

Triclinic. Axes $a : b : c = 0{\cdot}6347 : 1 : 0{\cdot}5501$; $\alpha = 93° 13'$, $\beta = 115° 55\frac{1}{2}'$, $\gamma = 91° 12'$.

bc, $010 \wedge 001 = 85° 50'$.
mM, $110 \wedge \bar{1}10 = 59° 29'$.
bm, $010 \wedge 110 = 58° 4'$.
cm, $001 \wedge 110 = 65° 53'$.
cM, $001 \wedge 1\bar{1}0 = 69° 20'$.
cy, $001 \wedge \bar{2}01 = 81° 14'$.

793



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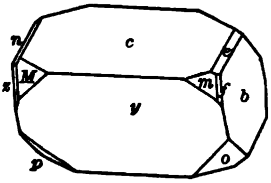


Twins as with albite (p. 462 and p. 464). Crystals usually prismatic $\|$ c axis (Fig. 793, also Fig. 364, p. 146), less often elongated $\|$ b axis, like pericline (Fig. 794). Also massive, cleavable, with granular or coarse lamellar structure.

Cleavage: c (001) perfect; b (010) somewhat less so. Fracture conchoidal to uneven. Brittle. H. = 6–6·5. G. = 2·74–2·76. Color white, grayish, reddish. Streak uncolored. Transparent to translucent.

Optically −. Ax. pl. nearly ⊥ *e* (021), and its trace inclined 60° to the edge *c*/*e* from left above behind to right in front below. Extinction-angles on *c* (001), −34° to −42° with edge *b*/*c*; on *b* (010), −35° to −43° (Fig. 784, p. 462). Dispersion $\rho < v$, also inclined. 2 V = 78°. α = 1·576. β = 1·584. γ = 1·588. Birefringence stronger than with albite.

Comp. — A silicate of aluminium and calcium, $CaAl_2Si_2O_8$ or $CaO.Al_2O_3.2SiO_2$ = Silica 43·2, alumina 36·7, lime 20·1 = 100. Soda (as $NaAlSi_3O_8$) is usually present in small amount, and as it increases there is a gradual transition through bytownite to labradorite.

Var. — *Anorthite* was described from the glassy crystals of Mte. Somma, Vesuvius; and *christianite* and *biotine* are the same mineral. *Thiorsauite* is the same from Iceland. *Indianite* is a white, grayish, or reddish granular anorthite from India, where it occurs as the gangue of corundum, first described in 1802 by Count Bournon. *Cyclopite* occurs in small, transparent, and glassy crystals, tabular ∥ *b* (010), coating cavities in the dolerite of the Cyclopean Islands and near Trezza on Etna. *Amphodelite, lepolite, latrobite* also belong to anorthite.

Pyr., etc. — B.B. fuses at 5 to a colorless glass. Anorthite from Mte. Somma, and indianite from the Carnatic, India, are decomposed by hydrochloric acid, with separation of gelatinous silica.

Artif. — Anorthite is the easiest of the feldspars to be formed artificially. Unlike the alkalic feldspars it can be easily formed in a dry fusion of its constituents. This method becomes progressively more difficult as the albite molecule is added to the composition. Anorthite is frequently observed in slags and is easily produced in artificial magmas. It further is often produced when more complex silicates are broken down by fusion.

Obs. — Occurs in some diorites; occasionally in connection with gabbro and serpentine rocks; in some cases along with corundum; in many volcanic rocks, andesites, basalts, etc.; as a constituent of some meteorites (Juvenas, Stannern).

Anorthite (*christianite* and *biotine*) occurs at Mount Vesuvius in isolated blocks among the old lavas in the ravines of Monte Somma; in the Albani Mts.; on the Pesmeda Alp, Monzoni, Tyrol, as a contact mineral; Aranyer Berg, Transylvania, in andesite; in Iceland; near Bogoslovsk in the Ural Mts. In the Cyclopean Islands (*cyclopite*). In the lava of the island of Miyake, Japan.

In crystals from Franklin, N. J.; from Phippsburg, Me.

Anorthite was named in 1823 by Rose from *ανορθός*, *oblique*, the crystallization being triclinic.

Anemousite. A feldspar having the composition, $Na_2O.2CaO.3Al_2O_3.9SiO_2$. This does not agree with any possible member of the albite-anorthite series. This is explained by assuming the presence in small amount of a sodium-anorthite molecule, $Na_2O.Al_2O_3.2SiO_2$, to which the name *carnegieite* has been given. Cleavage angle = 85° 59′. G. = 2·68. α = 1·555. β = 1·559. γ = 1·563. 2 V = 82° 48′. Found as loose crystals on Mte. Rosso, Island of Linosa. Name derived from the ancient Greek name of the island. *Carnegieite* is named in honor of Andrew Carnegie.

II. Metasilicates. $RSiO_3$

Salts of Metasilicic Acid, H_2SiO_3; characterized by an oxygen ratio of 2 : 1 for silicon to bases. The Division closes with a number of species, in part of somewhat doubtful composition, forming a transition to the Orthosilicates.

The metasilicates include two prominent and well-characterized groups, viz., the Pyroxene Group and the Amphibole Group. There are also others less important.

Leucite Group. Isometric

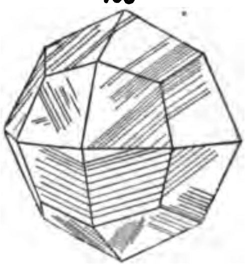
In several respects leucite is allied to the species of the FELDSPAR GROUP, which immediately precede.

Leucite	$KAl(SiO_3)_2$	Isometric at 500°
	Pseudo-isometric at ordinary temperatures.	
Pollucite	$H_2Cs_4Al_4(SiO_3)_9$	Isometric

LEUCITE. Amphigène.

Isometric at 500° C.; pseudo-isometric under ordinary conditions (see p. 302). Commonly in crystals varying in angle but little from the tetragonal trisoctahedron *n* (211), sometimes with *a* (100), and *d* (110) as subordinate forms. Faces often showing fine striations due to twinning (Fig. 795). Also in disseminated grains; rarely massive granular.

795



Cleavage: *d* (110) very imperfect. Fracture conchoidal. Brittle. H. = 5·5–6. G. = 2·45–2·50. Luster vitreous. Color white, ash-gray or smoke-gray. Streak uncolored. Translucent to opaque. Usually shows very feeble double refraction: ω = 1·508, ϵ = 1·509 (p. 302).

Comp. — $KAl(SiO_3)_2$ or $K_2O.Al_2O_3.4SiO_2$ = Silica 55·0, alumina 23·5. potash 21·5 = 100.

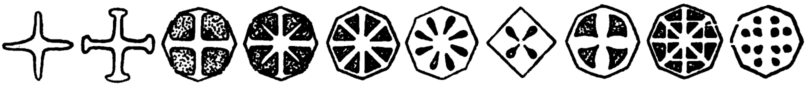
Soda is present only in small quantities, unless as introduced by alteration; traces of lithium, also of rubidium and cæsium, have been detected. Leucite and analcite are closely related chemically as is shown by the fact that the two species can be converted into each other when heated with sodium or potassium chlorides or carbonates.

Pyr., etc. — B.B. infusible; with cobalt solution gives a blue color (aluminium). Decomposed by hydrochloric acid without gelatinization.

Diff. — Characterized by its trapezohedral form, absence of color, and infusibility. It is softer than garnet and harder than analcite; the latter yields water and fuses.

Micro. — Recognized in thin sections by its extremely low refraction, isotropic character, and the symmetrical arrangement of inclusions (Fig. 796; also Fig. 485, p. 180). Larger crystals are commonly not wholly isotropic and, further, show complicated systems of twinning-lines (Fig. 795); the birefringence is, however, very low, and the colors scarcely rise above dark gray; they are best seen by introduction of the quartz or gypsum plate yielding red of the first order. The smaller leucites, which lack this twinning or the inclusions, are only to be distinguished from sodalite or analcite by chemical tests.

796



Leucite crystals from the leucitite of the Bearpaw Mts., Montana (Pirsson). These show the progressive growth from skeleton forms to complete crystals with glass inclusions.

Artif. — Leucite is easily prepared artificially by simply fusing together its constituents in proper proportion and allowing the melt to crystallize slowly. The addition of potassium vanadate produces larger crystals. Leucite has been formed when microcline and biotite were fused together and also when muscovite was fused alone.

Obs. — Leucite occurs only in igneous rocks, and especially in recent lavas, as one of the products of crystallization of magmas rich in potash and low in silica (for which reason this species rather than orthoclase is formed). The larger embedded crystals are commonly anisotropic and show twinning lamellæ; the smaller ones, forming the groundmass, are isotropic and without twinning. Found in leucitites and leucite-basalts, leucitophyres, leucite-phonolites and leucite-tephrites; also in certain rocks occurring in dikes. Very rare in intruded igneous rocks, only one or two instances being known; but its former presence under such conditions is indicated by pseudomorphs, often of large size (*pseudoleucite*) consisting of nephelite and orthoclase, also of analcite.

The prominent localities are, first of all, Vesuvius and Mte. Somma, where it is thickly disseminated through the lava in grains, and in large perfect crystals; also in ejected masses; also near Rome, at Capo di Bove, Rocca Monfina, etc. Further in leucite-tephrite at Proceno near Lake Bolsena in central Italy; in Germany about the Laacher See and at several points in the Eifel; at Rieden near Andernach; at Meiches in the Vogelsgebirge; in the Kaiserstuhlgebirge; Wiesental, Bohemia. Occurs in Brazil, at Pinhalzinho. From the Cerro de las Virgines, Lower California. In the United States it is present in a rock in the Green River Basin at the Leucite Hills, Wy.; also in the Absaroka range, in northwestern Wy.; in the Highwood and Bearpaw Mts., Mon. (in part pseudoleucite). On the shores of Vancouver Island, where magnificent groups of crystals have been found as drift boulders.

Pseudoleucite (see above) occurs in the phonolite (tinguaite) of the Serra de Tingua, Brazil; at Magnet Cove, Ark.; near Hamburg, N.J.; Mon.; also in the Cariboo District, British Columbia.

Named from λευκός, *white*, in allusion to its color.

Pollucite. Essentially $H_2O.2Cs_2O.2Al_2O_3.9SiO_2$. Isometric; often in cubes; also massive. H. = 6·5. G. = 2·901. Colorless. n = 1·525. Occurs very sparingly in the island of Elba, with petalite (castorite); also at Hebron and Rumford, Me.

Ussingite. $HNa_2Al(SiO_3)_3$. Triclinic. Three cleavages. G. = 2·5. H. = 6–7. Color reddish violet. Indices, 1·50–1·55. Easily fusible. Soluble in hydrochloric acid. Found in rolled masses from pegmatite at Kangerdluarsuk, Greenland.

Pyroxene Group

Orthorhombic, Monoclinic, Triclinic

Composition for the most part that of a metasilicate, $RSiO_3$, with R = Ca,Mg,Fe chiefly, also Mn,Zn. Further $RSiO_3$ with $\overset{II}{R}(Fe,Al)_2SiO_6$, less often containing alkalies (Na,K), and then $RSiO_3$ with $\overset{I}{R}Al(SiO_3)_2$. Rarely including zirconium and titanium, also fluorine.

α. **Orthorhombic Section**

		$a : b : c$	or	$b : a : c$
Enstatite	$MgSiO_3$	0·9702 : 1 : 0·5710		1·0307 : 1 : 0·5885
Bronzite	$(Mg,Fe)SiO_3$			
Hypersthene	$(Fe,Mg)SiO_3$	0·9713 : 1 : 0·5704		1·0319 : 1 : 0·5872

The second set of axial ratios, with a = 1, brings out the similarity of the form to the monoclinic species.

β. **Monoclinic Section**

	$a : b : c$	β
Pyroxene	1·0921 : 1 : 0·5893	74° 10′

I. *NON-ALUMINOUS VARIETIES:*

1. DIOPSIDE	$CaMg(SiO_3)_2$ $Ca(Mg,Fe)(SiO_3)_2$
Malacolite, Salite, Diallage, etc.	
2. HEDENBERGITE	$CaFe(SiO_3)_2$
Manganhedenbergite	$Ca(Fe,Mn)(SiO_3)_2$
3. SCHEFFERITE	$(Ca,Mg)(Fe,Mn)(SiO_3)_2$
Jeffersonite	$(Ca,Mg)(Fe,Mn,Zn)(SiO_3)_2$

II. *ALUMINOUS VARIETIES:*

4. AUGITE $\begin{cases} Ca(Mg,Fe)(SiO_3)_2 \\ \text{with } (Mg,Fe)(Al,Fe)_2SiO_6 \end{cases}$

Leucaugite, Fassaite, Ægirite-augite.

		a : *b* : *c*	*β*
Acmite (Ægirite)	$Na\overset{III}{Fe}(SiO_3)_2$	1·0996 : 1 : 0·6012	73° 11′
Spodumene	$LiAl(SiO_3)_2$	1·1238 : 1 : 0·6355	69° 40′
Jadeite	$NaAl(SiO_3)_2$	1·103 : 1 : 0·613	72° 44½′
		a : *b* : *c*	*β*
Wollastonite	$CaSiO_3$	1·0531 : 1 : 0·9676	84° 30′
Pectolite	$HNaCa_2(SiO_3)_3$	1·1140 : 1 : 0·9864	84° 40′

γ. Triclinic Section

		a : *b* : *c*	*α*	*β*	*γ*
Rhodonite	$MnSiO_3$	1·0729 : 1 : 0·6213	103° 18′	108° 44′	81° 39′
	also $(Mn,Ca)SiO_3$ $(Mn,Fe)SiO_3$ $(Mn,Zn,Fe,Ca)SiO_3$				
Babingtonite	$(Ca,Fe,Mn)SiO_3.Fe_2(SiO_3)_3$	1·0691 : 1 : 0·6308	104° 21½′	108° 31′	83° 34′

The rare species Rosenbuschite, Låvenite, Wöhlerite also belong under the monoclinic section and Hiortdahlite under the triclinic section of this group.

The PYROXENE GROUP embraces a number of species which, while falling in different systems — orthorhombic, monoclinic, and triclinic — are yet closely related in form. Thus all have a fundamental prism with an angle of 93° and 87°, parallel to which there is more or less distinct cleavage. Further, the angles in other prominent zones show a considerable degree of similarity. In composition the metasilicates of calcium, magnesium, and ferrous iron are most prominent, while compounds of the form $\overset{II}{R}(Al,\overset{III}{Fe})_2SiO_6$, $\overset{I}{R}Al(SiO_3)_2$ are also important.

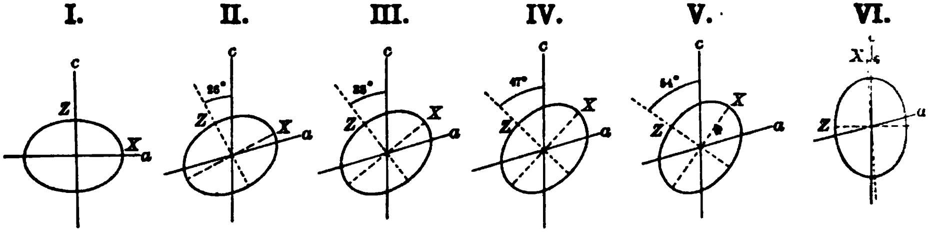
The species of the pyroxene group are closely related in composition to the corresponding species of the amphibole group, which also embraces members in the orthorhombic, monoclinic, and triclinic systems. In a number of cases the same chemical compound appears in each group; furthermore, a change by paramorphism of pyroxene to amphibole is often observed. In form also the two groups are related, as shown in the axial ratio; also in the parallel growth of crystals of monoclinic amphibole upon or about those of pyroxene (Fig. 461, p. 173). The axial ratios for the typical monoclinic species are:

Pyroxene	$a : b : c = 1·0921 : 1 : 0·5893$	$\beta = 74° 10'$
Amphibole	$a : \frac{1}{2}b : c = 1·1022 : 1 : 0·5875$	$\beta = 73° 58'$

See further on p. 486.

The optical relations of the prominent members of the Pyroxene Group, especially as regards the connection between the position of the ether-axes and the crystallographic axes are exemplified in the following figures (Cross). A corresponding exhibition of the prominent amphiboles is given under that group, Fig. 826, p. 486.

797



I, Enstatite, etc. II, Spodumene. III, Diopside, etc. IV, Hedenbergite, Augite. V, Augite. VI, Acmite.

α. Orthorhombic Section

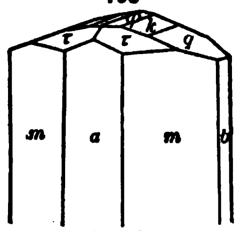
ENSTATITE.

Orthorhombic. Axes $a : b : c = 0{\cdot}9702 : 1 : 0{\cdot}5710$.

mm''', $110 \wedge 1\bar{1}0 = 88° 16'$. $\tau\tau'$, $223 \wedge \bar{2}23 = 40° 16\frac{1}{2}'$.
qq', $023 \wedge 0\bar{2}3 = \bar{2}41° 41'$. $\tau\tau'''$, $223 \wedge 2\bar{2}3 = 39° 1\frac{1}{2}'$.

Twins rare: tw. pl. *h* (014) as twinning lamellæ; also tw. pl. (101) as stellate twins crossing at angles of nearly 60°, sometimes six-rayed. Distinct crystals rare, habit prismatic. Usually massive, fibrous, or lamellar.

798



Bamle

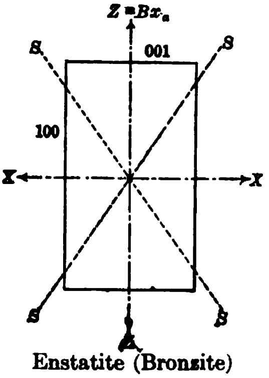
Cleavage: *m* (110) rather easy. Parting || *b* (010); also *a* (100). Fracture uneven. Brittle. H. = 5·5. G. = 3·1–3·3. Luster, a little pearly on cleavage-surfaces to vitreous; often metalloidal in the bronzite variety. Color grayish, yellowish or greenish white, to olive-green and brown. Streak uncolored, grayish. Translucent to nearly opaque. Pleochroism weak, more marked in varieties relatively rich in iron. Optically +. Ax. pl. || *b* (010). $Bx_a \perp c$ (001). Dispersion $\rho < v$ weak. Axial angle large and variable, increasing with the amount of iron, usually about 90° for FeO = 10 p. c. $\beta = 1{\cdot}669$; $\gamma - \alpha = 0{\cdot}009$.

Comp. — $MgSiO_3$ or $MgO.SiO_2$ = Silica 60, magnesia 40 = 100. Also $(Mg,Fe)SiO_3$ with Mg : Fe = 8 : 1, 6 : 1, 3 : 1, etc.

Var. — 1. *With little or no iron; Enstatite.* Color white, yellowish, grayish, or greenish white; luster vitreous to pearly; G. = 3·10–3·13. *Chladnite* (Shepardite of Rose), which makes up 90 p. c. of the Bishopville meteorite, belongs here and is the purest kind. *Victorite*, occurring in the Deesa meteoric iron in rosettes of acicular crystals, is similar.

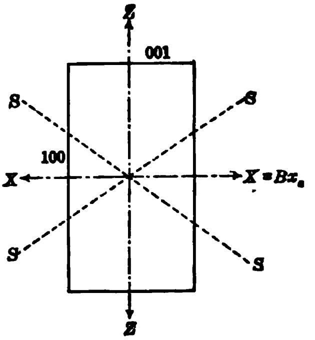
2. *Ferriferous; Bronzite.* Color grayish green to olive-green and brown. Luster on cleavage-surface often adamantine-pearly to submetallic or bronze-like; this, however, is usually of secondary origin and is

799



Enstatite (Bronzite)

800



Hypersthene

not essential. With the increase of iron (above 12 to 14 p. c.) bronzite passes to hypersthene, the optic axial angle changing so that in the latter X = Bx$_a$ ⊥ *a* (100). This is illustrated by Figs. 799, 800.

Pyr., etc. — B.B. almost infusible, being only slightly rounded on the thin edges; F. = 6. Insoluble in hydrochloric acid.

Artif. — Enstatite is formed from a melt having the proper composition at temperatures slightly under 1100°. At higher temperatures the monoclinic pyroxenes appear. Enstatite has also been formed by fusing olivine with silica. When serpentine is melted it breaks down into enstatite and olivine.

Micro. — In thin sections is colorless or light yellow or green; marked relief; prominent cleavage with parallel extinction; little pleochroism but becoming stronger with increase of iron; inclusions common lying parallel to brachypinacoid, producing characteristic schiller of mineral.

Obs. — Enstatite (including bronzite) is a common constituent of peridotites and the serpentines derived from them; it also occurs in crystalline schists. It is often associated in parallel growth with a monoclinic pyroxene, *e.g.*, diallage. A common mineral in meteoric stones often occurring in chondrules with eccentric radiated structure.

Occurs near Aloystal in Moravia, in serpentine; at Kupferberg in Bavaria; at Baste in the Harz Mts., Germany (*protobastite*); in the so-called olivine bombs of the Dreiser Weiher in the Eifel, Germany; in immense crystals, in part altered, at the apatite deposits of Kjörrestad near Bamle, Norway; in the peridotite associated with the diamond deposits of South Africa.

In the United States, in N. Y. at the Tilly Foster magnetite mine, Brewster, Putnam Co., with chondrodite and at Edwards; Texas, Pa.; bronzite from Webster, N. C.; Bare Hills, Baltimore, Md.

Named from ἐνστάτης, an *opponent*, because so refractory. The name *bronzite* has priority, but a bronze luster is not essential, and is far from universal.

HYPERSTHENE.

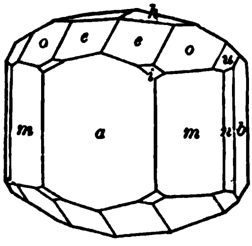
Orthorhombic. Axes $a : b : c = 0{\cdot}9713 : 1 : 0{\cdot}5704$.

mm''', 110 ∧ $1\bar{1}0$ = 88° 20′.   *oo'''*, 111 ∧ $1\bar{1}1$ = 52° 23′.
hh', 014 ∧ $0\bar{1}4$ = 16° 14′.   *uu'''*, 232 ∧ $2\bar{3}2$ = 72° 50′.

Crystals rare, habit prismatic, often tabular ‖ *a* (100), less often ‖ *b* (010). Usually foliated massive; sometimes in embedded spherical forms.

Cleavage: *b* (010) perfect; *m* (110) and *a* (100) distinct but interrupted. Fracture uneven. Brittle. H. = 5–6. G. = 3·40–3·50. Luster somewhat pearly on a cleavage-surface, and sometimes metalloidal. Color dark brownish green, grayish black, greenish black, pinchbeck-brown. Streak grayish, brownish gray. Translucent to nearly opaque. Pleochroism often strong, especially in the kinds with high iron percentage; thus ‖ X or *a* axis brownish red, Y or *b* axis reddish yellow, Z or *c* axis green. Optically −. Ax. pl. ‖ *b* (010). Bx$_a$ ⊥ *a* (100). Dispersion $\rho > v$. Axial angle rather large and

801



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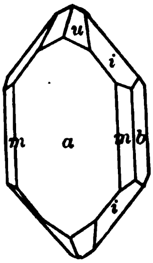

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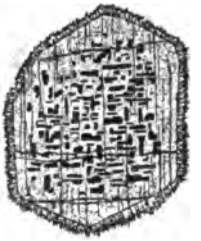


Figs. 801, *Amblystegite*, Laacher See. 802, Málnás. 803, Section ‖ *b* (010) showing inclusions; the exterior transformed to actinolite; from Lacroix.

variable, diminishing with increase of iron, cf. enstatite, p. 472, and Figs. 799, 800, p. 472. $\beta = 1{\cdot}702$; $\gamma - \alpha = 0{\cdot}013$.

Hypersthene often encloses minute tabular scales, usually of a brown color, arranged mostly parallel to the basal plane (Fig. 803), also less frequently vertical or inclined 30° to *c* axis; they may be brookite (göthite, hematite), but their true nature is doubtful. They are the cause of the peculiar metalloidal luster or schiller, and are often of secondary origin, being developed along the so-called "solution-planes" (p. 189).

Comp. — $(Fe,Mg)SiO_3$ with Fe : Mg = 1 : 3(FeO = 16·7 p. c.), 1 : 2 (FeO = 21·7 p. c.) to nearly 1 : 1(FeO = 31·0 p. c.). Alumina is sometimes present (up to 10 p. c.) and the composition then approximates to the aluminous pyroxenes.

Of the orthorhombic magnesium-iron metasilicates, those with FeO > 12 to 15 p. c. are usually to be classed with hypersthene, which is further characterized by being optically negative and having dispersion $\rho > v$.

Pyr., etc. — B.B. fuses to a black enamel, and on charcoal yields a magnetic mass; fuses more easily with increasing amount of iron. Partially decomposed by hydrochloric acid.

Micro. — In thin sections similar to enstatite except shows distinct reddish or greenish color with stronger pleochroism and is optically −.

Artif. — Similar to enstatite, which see.

Obs. — Hypersthene, associated with a triclinic feldspar (labradorite), is common in certain granular eruptive rocks, as norite, hyperite, gabbro, also in some andesites (*hypersthene-andesite*), a rock shown to occur rather extensively in widely separated regions.

It occurs at Isle St. Paul, Labrador; in Greenland; at Farsund and elsewhere in Norway; Elfdalen in Sweden; Penig in Saxony; Ronsberg in Bohemia; the Tyrol; Neurode in Silesia; Bodenmais, Bavaria. *Amblystegite* is from the Laacher See, Germany. *Szaboite* occurs with pseudobrookite and tridymite, in cavities in the andesite of the Aranyer Berg, Transylvania, and elsewhere.

Occurs in the norites of the Cortlandt region on the Hudson river, N. Y.; also common with labradorite in the Adirondack Archæan region of northern N. Y. and northward in Canada. In the hypersthene-andesites of Mt Shasta, Cal.; Buffalo Peaks, Col., and other points.

Hypersthene is named from ὑπέρ and σθένος, *very strong*, or *tough*.

BASTITE, or SCHILLER SPAR. An altered enstatite (or bronzite) having approximately the composition of serpentine. It occurs in foliated form in certain granular eruptive rocks and is characterized by a bronze-like metalloidal luster or schiller on the chief cleavage-face *b* (010), which "schillerization" (p. 251) is of secondary origin. H. = 3·5–4. G. = 2·5–2·7. Color leek-green to olive- and pistachio-green, and pinchbeck-brown. Pleochroism not marked. Optically −. Double refraction weak. Ax. pl. ∥ *a* (010) (hence normal to that of enstatite). $Bx_a \perp b$ (010). Dispersion $\rho > v$. The original bastite was from Baste near Harzburg in the Harz Mts., Germany; also from Todtmoos in the Schwarzwald, Germany.

PECKHAMITE, $2(Mg,Fe)SiO_3.(Mg,Fe)SiO_4$. Occurs in rounded nodules in the meteorite of Estherville, Emmet Co., Iowa, May 10, 1879. G. = 3·23. Color light greenish yellow.

β. Monoclinic Section

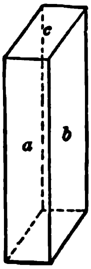
PYROXENE.

Monoclinic. Axes $a : b : c = 1{\cdot}0921 : 1 : 0{\cdot}5893$; $\beta = 74° 10'$.

mm''', $110 \wedge 1\bar{1}0 = 92° 50'$.
ca, $001 \wedge 100 = 74° 10'$.
cp, $001 \wedge \bar{1}01 = 31° 20'$.
ee', $011 \wedge 0\bar{1}1 = 59° 6'$.
zz', $021 \wedge 0\bar{2}1 = 97° 11'$.
cu, $001 \wedge 111 = 33° 49\tfrac{1}{2}'$.
cv, $001 \wedge 221 = 49° 54'$.
cn, $001 \wedge 110 = 79° 9\tfrac{1}{2}'$.
cs, $001 \wedge \bar{1}11 = 42° 2'$.
uu', $111 \wedge 1\bar{1}1 = 48° 29'$.
ss', $\bar{1}11 \wedge \bar{1}\bar{1}1 = 59° 11'$.
oo', $\bar{2}21 \wedge \bar{2}\bar{2}1 = 84° 11'$.

Twins: tw. pl. (1) *a* (100), contact-twins, common (Fig. 810), sometimes polysynthetic. (2) *c* (001), as twinning lamellæ producing striations on the vertical faces and pseudocleavage or parting ∥ *c* (Fig. 811); very common, often secondary. (3) y (101) cruciform-twins, not common (Fig. 451, p. 171). (4) W ($\bar{1}22$) the vertical axes crossing at angles of nearly 60°; sometimes repeated as a six-rayed star (Fig. 450, p. 171). Crystals usually prismatic in habit, often short and thick, and either a square prism (a (100), b (010) prominent), or nearly square (93°, 87°) with m (110) predominating; sometimes a nearly symmetrical 8-sided prism with a, b, m (Fig. 811). Often coarsely lamellar, || c (001) or a (100). Also granular, coarse or fine; rarely fibrous or columnar.

804



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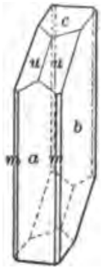

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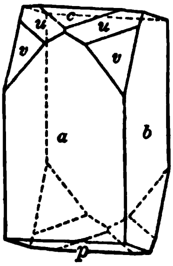

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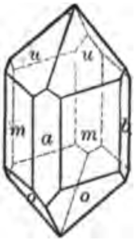

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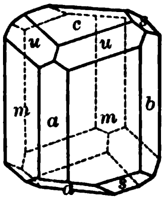

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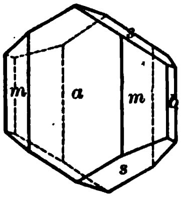

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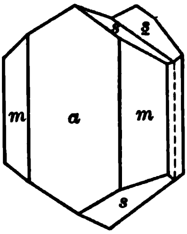

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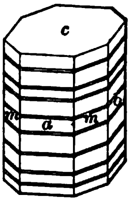

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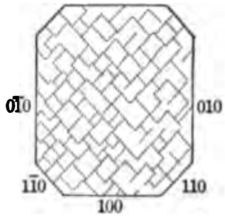
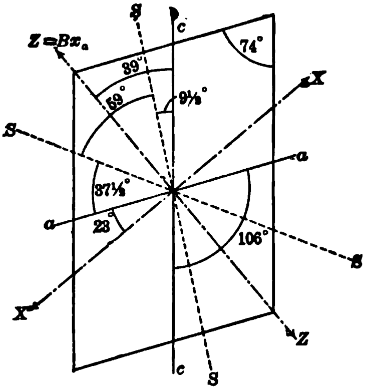


Cleavage: m (110) sometimes rather perfect, but interrupted, often only observed in thin sections ⊥ c axis (Fig. 812). Parting || c (001), due to twinning, often prominent, especially in large crystals and lamellar masses (Fig. 811); also || a (100) less distinct and not so common. Fracture uneven to conchoidal. Brittle. H. = 5–6. G. = 3·2–3·6, varying with the composition. Luster vitreous inclining to resinous; often dull; sometimes pearly || c(001) in kinds showing parting. Color usually green of various dull shades, varying from nearly colorless, white, or grayish white to brown and black; rarely bright green, as in kinds containing chromium; also blue. Streak white to gray and grayish green. Transparent to opaque. Pleochroism usually weak, even in dark-colored varieties; sometimes marked, especially in violet-brown kinds containing titanium. (*Violaite* is name given to a highly pleochroic variety from the Caucasus Mts.)

813



Optically +. Birefringence strong, $(\gamma - \alpha) = 0{\cdot}02 - 0{\cdot}03$. Ax. pl. ∥ b (010). Bx_a or $Z \wedge c$ axis = +36° in diopside, to +52° in augite (which see), or $Z \wedge c$ (001) = 20° to 36°, the angle in general increasing with amount of iron. For diopside 2 V = 59°. $\alpha = 1{\cdot}673$. $\beta = 1{\cdot}680$. $\gamma = 1{\cdot}702$.

Comp. — For the most part a normal metasilicate, $RSiO_3$, chiefly of calcium and magnesium, also iron, less often manganese and zinc. The alkali metals potassium and sodium present rarely, except in very small amount. Also in certain varieties containing the trivalent metals aluminium, ferric iron, and manganese. These last varieties may be most simply considered as molecular compounds of $Ca(Mg,Fe)Si_2O_6$ and $(Mg,Fe)(Al,Fe)_2SiO_6$, as suggested by Tschermak. Chromium is sometimes present in small amount; also titanium replacing silicon.

The name *Pyroxene* is from πυρ, *fire* and ξένος, *stranger*, and records Haüy's idea that the mineral was, as he expresses it, "a stranger in the domain of fire," whereas, in fact, it is, next to the feldspars, the most universal constituent of igneous rocks.

The varieties are numerous and depend upon variations in composition chiefly; the more prominent of the varieties properly rank as sub-species.

Artif. — The monoclinic pyroxene, $MgSiO_3$, can be crystallised from a melt having the theoretical composition at temperatures about 1500° or at a lower temperature from solution in molten calcium or magnesium vanadate. It is the most stable form of $MgSiO_3$. It has no true melting point but at about 1550° breaks down into forsterite and silica.

I. *Containing little or no Aluminium*

1. **Diopside.** Malacolite, Alalite. *Calcium-magnesium pyroxene.* Formula $CaMg(SiO_3)_2$ = Silica 55·6, lime 25·9, magnesia 18·5 = 100. Color white, yellowish, grayish white to pale green, and finally to dark green and nearly black; sometimes transparent and colorless, also rarely a fine blue. In prismatic crystals, often slender; also granular and columnar to lamellar massive. G. = 3·2–3·38. $Bx_a \wedge c$ axis = + 36° and upwards. $\gamma - \alpha = 0{\cdot}03$. Iron is present usually in small amount as noted below, and the amount increases as it graduates toward true hedenbergite.

The following belong here: *Chrome-diopside*, contains chromium (1 to 2·8 p. c. Cr_2O_3), often a bright green.

Malacolite, as originally described, was a pale-colored translucent variety from Sala, Sweden.

Alalite occurs in broad right-angled prisms, colorless to faint greenish or clear green, from the Mussa Alp in the Ala valley, Piedmont, Italy.

Traversellite, from Traversella, Piedmont, Italy, is similar.

Violan is a fine blue diopside from St. Marcel, Piedmont, Italy; occurring in prismatic crystals and massive.

Canaanite is a grayish-white or bluish-white pyroxene rock occurring with dolomite at Canaan, Conn.

Lavrovite is a pyroxene, colored green by vanadium, from the neighborhood of Lake Baikal, in eastern Siberia.

Diopside is named from δις, *twice* or *double*, and ὄψις, *appearance*. Malacolite is from μαλακός, *soft*, because softer than feldspar, with which it was associated.

2. **Hedenbergite.** *Calcium-iron pyroxene.* Formula $CaFe(SiO_3)_2$ = Silica 48·4, iron protoxide 29·4, lime 22·2 = 100. Color black. In crystals, and also lamellar massive. G. = 3·5–3·58. $Bx_a \wedge c$ axis = + 48°. Manganese is present in *manganhedenbergite* to 6·5 p. c. Color grayish green. G. = 3·55.

Between the two extremes, diopside and hedenbergite, there are numerous transitions conforming to the formula $Ca(Mg,Fe)Si_2O_6$. As the amount of iron increases the color changes from light to dark green to nearly black, the specific gravity increases from 3·2 to 3·6, and the angle $Bx_a \wedge c$ axis also from 36° to 48°.

The following are varieties, coming under these two sub-species, based in part upon structure, in part on peculiarities of composition.

Salite (Sahlite), color grayish green to deep green and black; sometimes grayish and yellowish white; in crystals; also lamellar (parting ∥ *c* (001)), and granular massive; from Sala in Sweden. *Baikalite*, a dark dingy green variety, in crystals, with parting ∥ *c* (001), from Lake Baikal, in Siberia.

Coccolite is a granular variety, embedded in calcite, also forming loosely coherent to compact aggregates; color varying from white to pale green to dark green, and then containing considerable iron; the latter the original coccolite. Named from *κόκκος*, a *grain*.

DIALLAGE. A lamellar or thin-foliated pyroxene, characterized by a fine lamellar structure and parting ∥ *a* (100), with also parting ∥ *b* (010), and less often ∥ *c* (001). Also a fibrous structure ∥ *c* axis. Twinning ∥ *a* (100), often polysynthetic; interlamination with an orthorhombic pyroxene common. Color grayish green to bright grass-green, and deep green; also brown. Luster of surface *a* (100) often pearly, sometimes metalloidal or exhibiting schiller and resembling bronzite, from the presence of microscopic inclusions of secondary origin. $Bx_a \wedge c$ axis = + 39 to 40°; $\beta = 1·681$; $\gamma - \alpha = 0·024$. H. = 4; G. = 3·2–3·35. In composition near diopside, but often containing alumina and sometimes in considerable amount, then properly to be classed with the augites. Often changed to amphibole, see smaragdite, and uralite, p. 490. Named from *διαλλαγή*, *difference*, in allusion to the dissimilar planes of fracture. This is the characteristic pyroxene of gabbro, and other related rocks.

Omphacite. The granular to foliated pyroxenic constituent of the garnet-rock called eclogite, often interlaminated with amphibole (smaragdite); color grass-green. Contains some Al_2O_3.

3. SCHEFFERITE. A manganese pyroxene, sometimes also containing much iron. Color brown to black.

In crystals, sometimes tabular ∥ *c* (001), also with *p* ($\bar{1}01$) prominent, more often elongated in the direction of the zone *b* (010) : *p* ($\bar{1}01$), rarely prismatic, ∥ *c* axis. Twins, with *a* (100) as tw. pl. very common. Also crystalline, massive. Cleavage prismatic, very distinct. Color yellowish brown to reddish brown; also black (*iron-schefferite*). Optically +. Bx_a or $Z \wedge c$ axis = 44° 25½′. The iron-schefferite from Pajsberg, Sweden, is black in color and has $Z \wedge c$ axis = + 49° to 59° for different zones in the same crystal. The brown iron-schefferite (*urbanite*) from Långban, Sweden, has $Z \wedge c$ axis = 69° 3′. It resembles garnet in appearance.

Jeffersonite is a manganese-zinc pyroxene from Franklin Furnace, N. J. (but the zinc may be due to impurity). In large, coarse crystals with edges rounded and faces uneven. Color greenish black, on the exposed surface chocolate-brown.

Blanfordite. A pyroxene containing some sodium, manganese and iron. Strongly pleochroic (rose-pink to sky-blue). Found with manganese ores in the Central Provinces, India.

Clinoenstatite has been suggested as the name for the monoclinic magnesium pyroxene.

II. *Aluminous*

4. AUGITE. *Aluminous pyroxene.* Composition chiefly $CaMgSi_2O_6$ with $(Mg,Fe)(Al,Fe)_2SiO_6$, and occasionally also containing alkalies and then graduating toward acmite. Titanium is also sometimes present. Here belong:

a. LEUCAUGITE. Color white or grayish. Contains alumina, with lime and magnesia, and little or no iron. Looks like diopside. H. = 6·5; G. = 3·19. Named from *λευκός*, *white*.

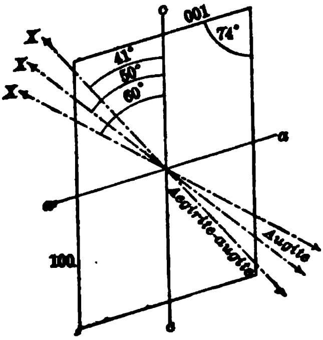
b. FASSAITE. Includes the pale to dark, sometimes deep-green crystals, or pistachio-green and then resembling epidote. The aluminous kinds of diallage also belong here. Named from the locality in the Fassatal, Tyrol. *Pyrgom* is from *πύργωμα*, *a tower*.

c. AUGITE. Includes the greenish or brownish black and black kinds, occurring mostly in eruptive rocks. It is usually in short prismatic crystals, thick and stout, or tabular ∥ *a* (100); often twins (Figs. 809, 810). Ferric iron is here present, in a relatively large amount, and the angle $Bx_a \wedge c$ axis becomes + 50° to 52°. $\beta = 1·717$; $\gamma - \alpha = 0·022$. TiO_2 is present in some kinds, which are then pleochroic. Named from *αυγή*, *luster*.

d. ALKALI-AUGITE. Here belong varieties of augite characterized by the presence of alkalies, especially soda; they approximate in composition and optically to acmite and ægirite ($Bx_a \wedge c$ axis = 60°, Fig. 814), and are sometimes called ægirite-augite (cf. Fig. 818,

p. 480). Known chiefly from rocks rich in alkalies, as elæolite-syenite, phonolite, leucitite, etc.

814



Pyr., etc. — Varying widely, owing to the wide variations in composition in the different varieties, and often by insensible gradations. Fusibility, 3·75 in diopside; 3·5 in salite, baikalite, and omphacite; 3 in jeffersonite and augite; 2·5 in hedenbergite. Varieties rich in iron afford a magnetic globule when fused on charcoal, and in general the fusibility varies with the amount of iron. Many varieties give with the fluxes reactions for manganese. Most varieties are unacted upon by acids.

Diff. — Characterized by monoclinic crystallization and the prismatic angle of 87° and 93°, hence yielding nearly square prisms; these may be mistaken for scapolite if terminal faces are wanting or indistinct (but scapolite fuses easily B. B. with intumescence). The oblique parting (∥ *c* (001), Fig. 811) often distinctive, also the common dull green to gray and brown colors. Amphibole differs in prismatic angle (55½° and 124½°) and cleavage, and in having common columnar to fibrous varieties, which are rare with pyroxene. (See also p. 486.)

Micro. — The common rock-forming pyroxenes are distinguished in thin sections by their high relief; usually greenish to olive tones of color; distinct system of interrupted cleavage-cracks crossing one another at nearly right angles in sections ⊥ *c* axis (Fig. 812); high interference-colors; general lack of pleochroism; large extinction-angle, 35° to 50° and higher, for sections ∥ *b* (010). The last-named sections are easily recognized by showing the highest interference colors; yielding no optical figures in convergent light and having parallel cleavage-cracks, the latter in the direction of the vertical axis. See also ægirite, p. 480.

A zonal banding is common, the successive laminæ sometimes differing in extinction-angle and pleochroism; also the hour-glass structure occasionally distinct (Fig. 815, from Lacroix).

815

Obs. — Pyroxene is a very common mineral in igneous rocks, being the most important of the ferromagnesian minerals. Some rocks consist almost entirely of pyroxene. It most commonly occurs in volcanic rocks but is found also, but less abundantly, in connection with granitic rocks. It is a common mineral in crystalline limestone and dolomite, in serpentine and metamorphic schists; sometimes forms large beds or veins, especially in Archæan rocks. It occurs also in meteorites. The pyroxene of limestone is mostly white and light green or gray in color, falling under *diopside* (malacolite, salite, coccolite); that of most other metamorphic rocks is sometimes white or colorless, but usually green of different shades, from pale green to greenish black, and occasionally black; that of serpentine is sometimes in fine crystals, but often of the foliated green kind called *diallage;* that of eruptive rocks is usually the black to greenish black *augite.*

In limestone the associations are often amphibole, scapolite, vesuvianite, garnet, orthoclase, titanite, apatite, phlogopite, and sometimes brown tourmaline, chlorite, talc, zircon, spinel, rutile, etc.; and in other metamorphic rocks mostly the same. In eruptive rocks it may be in distinct embedded crystals, or in grains without external crystalline form; it often occurs with similarly disseminated chrysolite (olivine), crystals of orthoclase (sanidine), labradorite, leucite, etc.; also with a rhombic pyroxene, amphibole, etc.

Pyroxene, as an essential rock-making mineral, is especially common in basic eruptive rocks. Thus, as augite, with a triclinic feldspar (usually labradorite), magnetite, often chrysolite, in basalt, basaltic lavas and diabase; in andesite; also in trachyte; in peridotite and pikrite; with nephelite in phonolite. Further with elæolite, orthoclase, etc., in elæolite-syenite and augite-syenite; also as diallage in gabbro; in many peridotites and the serpentines formed from them; as diopside (malacolite) in crystalline schists. In limburgite, augitite and pyroxenite, pyroxene is present as the prominent constituent, while feldspar is absent; it may also form rock masses alone nearly free from associated minerals.

Diopside (alalite, mussite) occurs in fine crystals on the Mussa Alp in the Ala valley in Piedmont, Italy, associated with garnets (hessonite) and talc in veins traversing serpentine; in fine crystals at Traversella, Piedmont; at Zermatt in Switzerland; Schwarzenstein in the Zillertal, Ober-Sulzbachtal, and elsewhere in Tyrol and in the Salzburg Alps; Reichenstein, Silesia, Germany; Ober-Sulzbachtal and elsewhere in Tyrol and in the Salzburg Alps; Reichenstein Lake; Rezbánya, Hungary; Achmatovsk in the Ural Mts., with almandite, clinochlore; Lake Baikal (*baikalite*) in eastern Siberia; Pargas in Finland; at Nordmark, Sweden.

Hedenbergite is from Tunaberg and Nordmark, Sweden; Arendal, Norway. Mangan-hedenbergite from Vester Silfberg, Sweden; *schefferite* from Långban, Sweden.

Augite (including fassaite) occurs on the Pesmeda Alp, Mt. Monzoni, and elsewhere in the Fassatal, Tyrol, as a contact formation; at Carlsbad and Teplitz, Bohemia; Traversella, Piedmont, Italy; the Laacher See, Eifel and Sasbach in the Kaiserstuhl, Germany; in Italy at Vesuvius, white rare, green, brown, yellow to black, Frascati, Etna; the Azores and Cape Verde Islands; the Hawaiian Islands, and many other regions of volcanic rocks.

In North America, occurs in Me., at Raymond and Rumford, diopside, salite, etc. In Vt., at Thetford, black augite, with chrysolite, in bowlders of basalt. In Conn., at Canaan, white crystals, often externally changed to tremolite, in dolomite; also the pyroxenic rock called *canaanite*. In N. Y., at Warwick, fine crystals; in Westchester Co., white, at the Sing Sing quarries; in Orange Co., in Monroe, at Two Ponds, crystals, often large, in limestone; near Greenwood furnace, and also near Edenville; in Lewis Co., at Diana, white and black crystals; in St. Lawrence Co., at Fine, in large crystals; at De Kalb, fine diopside; also at Gouverneur, Rossie, Russell, Pitcairn; at Moriah, coccolite, in limestone. In N. J., Franklin Furnace, Sussex Co., good crystals, also *jeffersonite*. In Pa., near Attleboro, crystals, and granular; in Pennsbury, at Burnett's quarry, diopside; at the French Creek mines, Chester Co., chiefly altered to fibrous amphibole. In Tenn., at the Ducktown mines.

In Canada, at Calumet Island, grayish green crystals in limestone; in Bathurst, colorless or white crystals; at Grenville, dark green crystals, and granular; Burgess, Lanark Co.; Renfrew Co., with apatite, titanite, etc.; crystals from Adams Lake, Ontario; Orford, Sherbrooke Co., white crystals, also of a chrome-green color with chrome garnet; at Hull and Wakefield, white crystals with nearly colorless garnets, honey-yellow vesuvianite, etc. At many other points in the Archæan of Quebec and Ontario, especially in connection with the apatite deposits.

Pyroxene undergoes alteration in different ways. A change of molecular constitution without essential change of composition, i.e., by *paramorphism* (using the word rather broadly), may result in the formation of some variety of amphibole. Thus, the white pyroxene crystals of Canaan, Conn., are often changed on the exterior to tremolite; similarly with other varieties at many localities. See *uralite*, p. 490. Also changed to steatite, serpentine, etc.

PIGEONITE, is the name given to a pyroxene with small and variable axial angle from Pigeon Point, Minn.

ACMITE. ÆGIRITE.

Monoclinic. Axes: $a : b : c = 1{\cdot}0996 : 1 : 0{\cdot}6012$; $\beta = 73° 11'$.

Twins: tw. pl. *a* (100) very common; crystals often polysynthetic, with enclosed twinning lamellæ. Crystals long prismatic, vertically striated or channeled; acute terminations very characteristic.

The above applies to ordinary *acmite*. For *ægirite*, crystals prismatic, bluntly terminated; twins not common; also in groups or tufts of slender acicular to capillary crystals, and in fibrous forms.

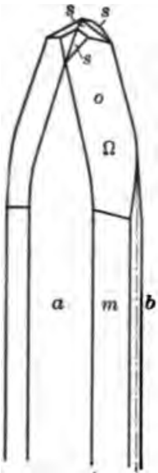
Cleavage: *m* (110) distinct; *b* (010) less so. Fracture uneven. Brittle. H. = 6–6·5. G. = 3·50–3·55. Luster vitreous, inclining to resinous. Streak pale yellowish gray. Color brownish or reddish brown, green; in the fracture blackish green. Subtransparent to opaque. Optically −. Ax. pl. || *b* (010). Bx_a or $X \wedge c$ axis $= +2\frac{1}{2}°$ acmite, to 6° ægirite. $\alpha = 1{\cdot}763$. $\beta = 1{\cdot}799$, $\gamma = 1{\cdot}813$.

Var. — Includes *acmite* in sharp-pointed crystals (Fig. 816) often twins. $Bx_a \wedge c$ axis $= 5\frac{1}{2}°–6°$. Also *ægirite* (Fig. 817) in crystals bluntly terminated, twins rare, $Bx_a \wedge c$ axis $= 2\frac{1}{2}°–3\frac{1}{2}°$.

Crystals of acmite often show a marked zonal structure, green within and brown on the exterior, particularly || *a* (100), *b* (010), *p* ($\bar{1}01$), *s* (111). The brown portion (acmite) is feebly pleochroic, the green (ægirite) strongly pleochroic. Both have absorption $X > Y > Z$, but the former has *X* light brown with tinge of green, *Y* greenish yellow with tinge of brown, Z brownish yellow; the latter has X deep grass-green, Y lighter grass-green, Z yellowish brown to yellowish.

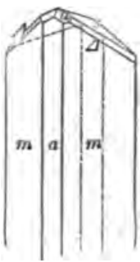
With some authors (vom Rath, etc.) s = (011) and $X \wedge c$ axis = $-2°$ to $-6°$, as in Fig. 819. Fig. 818 shows the optical orientation according to Brögger.

816



Acmite

817



Ægirite

Comp. — Essentially $Na\overset{III}{Fe}(SiO_3)_2$ or $Na_2O.Fe_2O_3.4SiO_2$ = Silica 52·0, iron sesquioxide 34·6, soda 13·4 = 100. Ferrous iron is also present.

Pyr., etc. — B.B. fuses at 2 to a lustrous black magnetic globule, coloring the flame deep yellow; with the fluxes reacts for iron and sometimes manganese. Slightly acted upon by acids.

Micro. — Ægirite is characterized in thin sections by its grass-green color; strong pleochroism in tones of green and yellow; the small extinction-angle in sections ∥ b(010). Distinguished from common green hornblende, with which it might be confounded, by the fact that in such sections the direction of extinction lying near the cleavage is negative (X), while the same direction in hornblende is positive (Z).

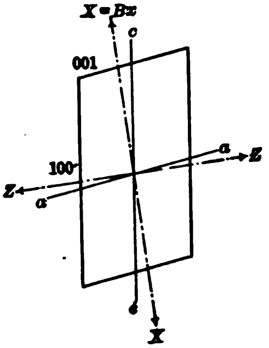
Artif. — Acmite can be produced artificially by fusing together its constituent oxides but usually under such conditions only a glass containing crystals of magnetite is formed.

Obs. — The original *acmite* occurs in a pegmatite vein; at Rundemyr, east of the little lake called Rokebergskjern, in the parish of Eker, near Kongsberg, Norway. It is in slender crystals, sometimes a foot long, embedded in feldspar and quartz.

Ægirite occurs especially in igneous rocks rich in soda and containing iron, commonly in rocks containing leucite or nephelite; thus in ægirite-granite, nephelite-syenite, and some varieties of phonolite; often in such cases iron-ore grains are wanting in the rock, their place being taken by ægirite crystals. In the sub-variety of phonolite called tinguaite, the rock has often a deep greenish color due to the abundance of minute crystals of ægirite. Large crystals are found in the pegmatite facies of nephelite-syenites as in West Greenland, Southern Norway, the peninsula Kola in Russian Lapland, Ditro in Transylvania.

Prominent American occurrences are the following: Magnet Cove, Ark. (large crystals); Salem and Quincy, Mass.; Libertyville, N. J. (dike); Trans Pecos district in Texas; Black Hills, S. D.; Cripple Creek, Col.; Bearpaw Mts., Judith Mts. and the Crazy Mts. in Mon.; also vanadium-bearing ægirites from Libby, Mon., also at Montreal, Canada.

818



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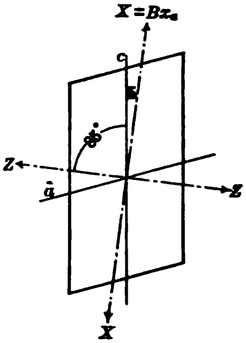


Acmite is named from ἄκμη, *point*, in allusion to the pointed extremities of the crystals; *Ægirite* is from Ægir, the Icelandic god of the sea.

SPODUMENE. Triphane.

Monoclinic. Axes $a : b : c$ = 1·1238 : 1 : 0·6355; β = 69° 40′.

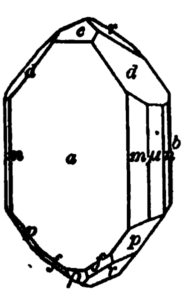
Twins: tw. pl. a (100). Crystals prismatic (mm''' 110 ∧ $1\bar{1}0$ = 93° 0′), often flattened ∥ a (100); the vertical planes striated and furrowed; crystals sometimes very large. Also massive, cleavable.

Cleavage m (110) perfect. A lamellar structure ∥ a (100) sometimes very prominent, a crystal then separating into thin plates. Fracture uneven to subconchoidal. Brittle. H. = 6·5–7. G. = 3·13–3·20. Luster vitreous, on cleavage surfaces somewhat pearly. Color greenish white, grayish white, yellowish green, emerald-green, yellow, amethystine purple. Streak white. Transparent to translucent. Pleochroism strong in deep green varieties. Optically +. Ax. pl. ‖ *b* (010). $Bx_a \wedge c$ axis = + 26°. Dispersion $\rho > v$, horizontal. 2 V = 58°. $\alpha = 1{\cdot}651$. $\beta = 1{\cdot}669$. $\gamma = 1{\cdot}677$.

Hiddenite has a yellow-green to emerald-green color; the latter variety is used as a gem. In small (½ to 2 inches long) slender prismatic crystals, faces often etched.

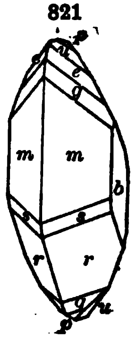
Kunzite is a clear lilac-colored variety found near Pala, San Diego Co., California, and also at Vanakarata, Madagascar. The unaltered material from Branchville, Conn., shows the same color. Used as a gem stone.

820



Norwich, Mass

821



Hiddenite

Comp. — $LiAl(SiO_3)_2$ or $Li_2O.Al_2O_3.4SiO_2$ = Silica 64·5, alumina 27·4, lithia 8·4 = 100. Generally contains a little sodium; the variety hiddenite also chromium, to which the color may be due.

Pyr., etc. — B.B. becomes white and opaque, swells up, imparts a purple-red color (lithia) to the flame (sometimes obscured by sodium), and fuses at 3·5 to a clear or white glass. Not acted upon by acids. Kunzite shows strong phosphorescence with an orange-pink color when excited by an oscillating electric discharge, by ultra violet rays, X-rays, or radium emanations.

Diff. — Characterized by its perfect parting ‖ *a* (100) (in some varieties) as well as by prismatic cleavage; has a higher specific gravity and more pearly luster than feldspar or scapolite. Gives a red flame B.B. Less fusible than amblygonite.

Alter. — Spodumene undergoes very commonly alteration. First by the action of solutions containing soda it is changed to a mixture of eucryptite, $LiAlSiO_4$, and albite, $NaAlSi_3O_8$. Later through the influence of potash salts the eucryptite is changed to muscovite. This resulting mixture of albite and muscovite is known as *cymatolite*, having a wavy fibrous structure and silky luster. These alteration products are well shown in the specimens from Branchville, Conn.

Artif. — An artificial spodumene has been obtained together with other silicates by fusing together lithium carbonate, alumina and silica. This spodumene differs, however, from the natural mineral in its optical properties and has been called *β-spodumene*. The natural mineral, or spodumene, is transformed into the β modification on heating to 1000°.

Obs. — Spodumene occurs in pegmatite veins, sometimes in crystals of very great size. Crystals from the Etta tin mine, S. D., with faces up to 40 feet in length have been reported. Occurs on the island of Utö, Sweden; at Killiney Bay, Ireland; in small transparent crystals of a pale yellow in Brazil, province of Minas Geraes. Variously colored spodumene from Madagascar.

In the United States, in granite at Goshen, Mass.; also at Chesterfield, Chester, Huntington (formerly Norwich), and Sterling, Mass.; at Windham, Me., with garnet and staurolite and at Peru, with beryl, triphylite, petalite. In Conn., at Branchville, the crystals often of immense size; near Stony Point, Alexander Co., N. C. (*hiddenite*); in S. D. at the Etta tin mine in Pennington Co. Kunzite from Pala, Cal.

The name spodumene is from *σποδιός, ash-colored*. *Hiddenite* is named for W. E. Hidden and *Kunzite* for Dr. G. F. Kunz.

Use. — The colored transparent varieties are used as gem stones; see above.

JADEITE.

Monoclinic. Axes, see p. 471. Cleavage and optical characters like pyroxene. Usually massive, with crystalline structure, sometimes granular, also obscurely columnar, fibrous foliated to closely compact.

Cleavage: prismatic, at angles of about 93° and 87°; also || *a* (100) difficult. Fracture splintery. Extremely tough. H. = 6·5–7. G. = 3·33–3·35. Luster subvitreous, pearly on surfaces of cleavage. Color apple-green to nearly emerald-green, bluish green, leek-green, greenish white, and nearly white; sometimes white with spots of bright green. Optically +. $Bx_a \wedge c$ axis = 30° to 40°. 2 V = 72°. $\beta = 1{\cdot}654$. Streak uncolored. Translucent to subtranslucent.

Comp. — Essentially a metasilicate of sodium and aluminium corresponding to spodumene, $NaAl(SiO_3)_2$ or $Na_2O.Al_2O_3.4SiO_2$ = Silica 59·4, alumina 25·2, soda 15·4 = 100.

Chloromelanite is a dark green to nearly black kind of jadeite (hence the name), containing iron sesquioxide and not conforming exactly to the above formula.

Pyr., etc. — B.B. fuses readily to a transparent blebby glass. Not attacked by acids after fusion, and thus differing from saussurite.

Obs. — Occurs chiefly in eastern Asia, thus in the Mogoung district in Upper Burma, in a valley 25 miles southwest of Meinkhoom, in rolled masses in a reddish clay; in Yungchang, province of Yunnan, southern China; in Thibet. Much uncertainty prevails, however, as to the exact localities, since jadeite and nephrite have usually been confused with each other. May occur also on the American continent, in Mexico and South America; perhaps also in Europe.

Jadeite has long been highly prized in the East, especially in China, where it is worked into ornaments and utensils of great variety and beauty. It is also found with the relics of early man, thus in the remains of the lake-dwellers of Switzerland, at various points in France, in Mexico, Greece, Egypt, and Asia Minor.

A pyroxene, resembling jadeite in structure and consisting of the molecules of jadeite, diopside, and acmite in nearly equal proportions, occurs at the manganese mines of St. Marcel, Italy.

Use. — As the material jade, is used as an ornamental stone. See below.

JADE is a general term used to include various mineral substances of tough, compact texture and nearly white to dark green color used by early man for utensils and ornaments, and still highly valued in the East, especially in China. It includes properly two species only; *nephrite*, a variety of amphibole (p. 489), either tremolite or actinolite, with G. = 2·95–3·0. and *jadeite*, of the pyroxene group and in composition a soda-spodumene, with G. = 3·3–3·35; easily fusible.

The jade of China belongs to both species, so also that of the Swiss lake-habitations and of Mexico. Of the two, however, the former, nephrite, is the more common and makes the jade (ax stone or Punamu stone) of the Maoris of New Zealand; also found in Alaska.

The name jade is also sometimes loosely used to embrace other minerals of more or less similar characters, and which have been or might be similarly used — thus sillimanite, pectolite, serpentine; also vesuvianite, garnet. Bowenite is a jade-like variety of serpentine. The "jade tenace" of de Saussure is now called saussurite.

WOLLASTONITE. Tabular Spar

Monoclinic. Axes $a : b : c = 1{\cdot}0531 : 1 : 0{\cdot}9676$; $\beta = 84° 30'$.

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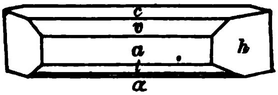

Diana, N. Y.

mm''', $110 \wedge 1\bar{1}0$ = 92° 42'.
hh''', $540 \wedge 5\bar{4}0$ = 79° 58'.
gg', $011 \wedge 0\bar{1}1$ = 87° 51'.
cv, $001 \wedge 101$ = 40° 3'.
cr, $001 \wedge \bar{3}01$ = 74° 59'.
ct, $001 \wedge \bar{1}01$ = 45° 5'.

Twins: tw. pl. *a* (100). Crystals commonly tabular || *a* (100) or *c* (001); also short prismatic. Usually cleavable massive to fibrous, fibers parallel or reticulated; also compact.

Cleavage: *a* (100) perfect; also *c* (001); *t* ($\bar{1}01$) less so. Fracture uneven. Brittle. H. = 4·5–5. G. = 2·8–2·9. Luster vitreous, on cleavage surfaces pearly. Color white, inclining to gray, yellow, red, or brown. Streak white. Subtransparent to translucent. Optically −. $Bx_a \wedge c$ axis = + 32°. Dispersion $\rho > v$, inclined distinct. Ax. pl. || b (010). 2 E = 70°; $\alpha = 1{\cdot}621$. $\beta = 1{\cdot}633$. $\gamma = 1{\cdot}635$.

Comp. — Calcium metasilicate, $CaSiO_3$ or $CaO.SiO_2$ = Silica 51·7, lime 48·3, = 100.

When wollastonite is heated above 1190° C. it develops a basal cleavage, becomes pseudo-hexagonal, optically positive, nearly uniaxial but probably monoclinic. This material has been called *pseudowollastonite*.

Pyr., etc. — B.B. fuses quietly to a white, almost glassy globule. With hydrochloric acid decomposed with separation of silica; most varieties effervesce slightly from the presence of calcite. Often phosphoresces.

Micro. — In thin sections wollastonite is colorless with a moderate relief and medium birefringence. The plane of the optic axes is usually normal to the elongation of the crystals.

Artif. — Wollastonite may be obtained artificially by heating a glass of the composition $CaSiO_3$ to between 800° and 1000°. At higher temperatures the pseudowollastonite modification is obtained.

Obs. — Wollastonite is found especially in granular limestone, and in regions of granite, as a contact formation; it is very rare in eruptive rocks. It is often associated with a lime garnet, diopside, etc.

Occurs in Hungary in the copper mines of Csiklowa in the Banat; at Pargas in Finland; at Harzburg in the Harz Mts., Germany; at Auerbach, Hesse, Germany, in granular limestone; at Vesuvius, rarely in fine crystals; on the islands of Elba and Santorin.

In the United States, in N. Y., at Willsborough; Diana, Lewis Co.; Bonaparte Lake, Lewis Co. In Pa., Bucks Co., 3 m. west of Attleboro; in Cal., at Crestmore. In Canada, at Grenville; at St. Jérôme and Morin, Quebec, with apatite.

Named after the English chemist, W. H. Wollaston (1766–1828).

Alamosite. Lead metasilicate, $PbSiO_3$. Closely related to wollastonite in crystal forms. Monoclinic. In radiating fibrous aggregates. Cleavage || b (010). G. = 6·5. H. = 4·5. Colorless or white. Refractive index about 1·96. Found near Alamos, Sonora, Mexico.

PECTOLITE.

Monoclinic. Axes $a : b : c = 1{\cdot}1140 : 1 : 0{\cdot}9864$; $\beta = 84° 40'$.

Commonly in close aggregations of acicular crystals; elongated || b axis, but rarely terminated. Fibrous massive, radiated to stellate.

Cleavage: a (100) and c (001) perfect. Fracture uneven. Brittle. H. = 5. G. = 2·68–2·78. Luster of the surface of fracture silky or subvitreous. Color whitish or grayish. Subtranslucent to opaque. Optically +. Ax. pl. and $Bx_a \perp b$ (010); Bx_o nearly $\perp a$ (100). 2 V = 60°. $\beta = 1{\cdot}61$.

Comp. — $HNaCa_2(SiO_3)_3$ or $H_2O.Na_2O.4CaO.6SiO_2$ = Silica 54·2, lime 33·8, soda 9·3, water 2·7 = 100.

Pectolite is sometimes classed with the hydrous species allied to the zeolites.

Pyr., etc. — In the closed tube yields water. B.B. fuses at 2 to a white enamel. Decomposed in part by hydrochloric acid with separation of silica as a jelly. Often gives out light when broken in the dark.

Obs. — A secondary mineral, occurring like the zeolites mostly in basic eruptive rocks, in cavities or seams; occasionally in metamorphic rocks. Found in Scotland near Edinburgh; at Kilsyth, Corstorphine Hill (*walkerite*); Island Skye. Also at Mt. Baldo and Mt. Monzoni in the Tyrol; at Niederkirchen, Bavaria (*osmelite*).

Occurs also at Bergen Hill, Paterson and Great Notch, N. J.; Lehigh Co., Pa.; compact at Isle Royale, Lake Superior; at Magnet Cove, Ark., in elæolite-syenite (*manganpectolite* with 4 p. c. MnO); compact, massive in Alaska, where used, like jade, for implements.

Schizolite. Like manganpectolite, $HNa(Ca,Mn)_2(SiO_3)_3$, but triclinic. In prismatic crystals. Two cleavages. H. = 5–5·5. G. = 3·0–3·1. Color light red to brown. From the nepheline syenite of Julianehaab, southern Greenland.

Rosenbuschite. Near pectolite, but contains zirconium. Index, 1·65. From Norway. In nephelite-syenite-porphyry, Red Hill, Moultonboro, N. H.

Wöhlerite. A zirconium-silicate and niobate of Ca, Na, etc. In prismatic, tabular crystals, yellow to brown. Indices, 1·700–1·726. Occurs in elæolite-syenite, on several islands of the Langesund fiord, near Brevik, in Norway. In syenite from Red Hill, N. H.

Låvenite. A complex zirconuim-silicate of Mn, Ca, etc., containing also F, Ti, Ta, etc. In yellow to brown prismatic crystals. Index, 1·750. Found on the island Låven in the Langesund fiord, southern Norway; also elsewhere in elæolite-syenite.

γ. Triclinic Section

RHODONITE.

Triclinic. Axes $a : b : c = 1\cdot07285 : 1 : 0\cdot6213$; $\alpha = 103° 18'$; $\beta = 108° 44'$; $\gamma = 81° 39'$.

Crystals usually large and rough with rounded edges. Commonly tabular ∥ *c* (001); sometimes resembling pyroxene in habit. Commonly massive, cleavable to compact; also in embedded grains.

Cleavage: *m* (110), *M* ($1\bar{1}0$) perfect; *c* (001) less perfect. Fracture conchoidal to uneven; very tough when compact. H. = 5·5–6·5. G. = 3·4–3·68. Luster vitreous; on cleavage surfaces somewhat pearly. Color light brownish red, flesh-red, rose-pink; sometimes greenish or yellowish, when impure; often black outside from exposure. Streak white. Transparent to translucent. Optically −. $\beta = 1\cdot73$.

Comp. — Manganese metasilicate, $MnSiO_3$ or $MnO.SiO_2$ = Silica 45·9, manganese protoxide 54·1 = 100. Iron, calcium (in *bustamite*), and occasionally zinc (in *fowlerite*) replace part of the manganese.

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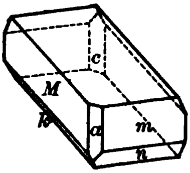

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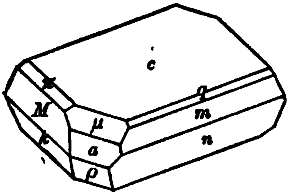

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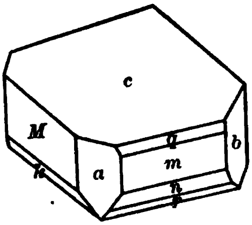

Franklin Furnace, N. J.

ab, 100 ∧ 010 = 94° 26′.
ac, 100 ∧ 001 = 72° 36½′.
bc, 010 ∧ 001 = 78° 42½′.
am, 100 ∧ 110 = 48° 33′.
mM, 110 ∧ $1\bar{1}0$ = 92° 28½′.
cn, 001 ∧ $\bar{2}\bar{2}1$ = 73° 52′.
ck, 001 ∧ $\bar{2}21$ = 62° 23′.
kn, $\bar{2}21$ ∧ $\bar{2}\bar{2}1$ = 86° 5′.

Pyr., etc. — B.B. blackens and fuses with slight intumescence at 2·5; with the fluxes gives reactions for manganese; fowlerite gives with soda on charcoal a reaction for zinc. Slightly acted upon by acids. The calciferous varieties often effervesce from mechanical admixture of calcium carbonate. In powder, partly dissolves in hydrochloric acid, and the insoluble part becomes of a white color. Darkens on exposure to the air, and sometimes becomes nearly black.

Diff. — Characterized by its pink color; distinct cleavages; hardness; fusibility and manganese reactions B.B.

Obs. — Occurs in Sweden at Långban, Wermland, in iron-ore beds, in broad cleavage-plates, and also granular massive, and at the Pajsberg iron mines near Filipstad (*paisbergite*) sometimes in small brilliant crystals; in the district of Ekaterinburg in the Ural Mts., massive like marble, whence it is obtained for ornamental purposes; with tetrahedrite at Kapnik and Rezbánya, Hungary; St. Marcel, Piedmont, Italy; Mexico (*bustamite*, containing CaO). In crystals from Broken Hill, New South Wales.

Occurs in Cummington, Mass.; on Osgood's farm, Blue Hill Bay, Me.; *fowlerite* (containing ZnO) at Mine Hill, Franklin Furnace, and Sterling Hill, near Ogdensburgh, N. J., usually embedded in calcite and sometimes in fine crystals.

Named from *ροδον, a rose,* in allusion to the color.

Rhodonite is often altered chiefly by oxidation of the MnO (as in *marceline, dyssnite*); also by hydration (*stratopeite, neotocite,* etc.); further by introduction of CO_2 (*allagite, photicite,* etc.).

Use. — Rhodonite at times is used as an ornamental stone.

Pyroxmangite. A triclinic, manganese-iron pyroxene. In cleavage masses. Indices, 1·75–1·76. H. = 5·5–6. G. = 3·8. Color, amber to dark brown. Easily fusible to black magnetic globule. Alters to *skemmatite.* Found near Iva, Anderson Co., South Carolina.

Babingtonite. $(Ca,Fe,Mn)SiO_3$ with $Fe_2(SiO_3)_3$. In small black triclinic crystals, near rhodonite in angle (axes on p. 471). H. = 5·5–6. G. = 3·35–3·37. Index, 1·72. From Arendal, Norway; at Herbornseelbach, Nassau, Germany; at Baveno, Italy. From Somerville and Athol, Mass.; in the zeolite deposits of Passaic Co., N. J.

Hiortdahlite. Essentially $(Na_2,Ca)(Si,Zr)O_3$, with also fluorine. In pale yellow tabular crystals (triclinic). Index, 1·695. Occurs sparingly on an island in the Langesund fiord, southern Norway.

Sobralite. A triclinic pyroxene. Optically +. Colorless. From eulysite rock at Södermanland, Sweden.

3. *Amphibole Group*

Orthorhombic, Monoclinic, Triclinic

Composition for the most part that of a metasilicate, $RSiO_3$, with R = Ca,Mg,Fe chiefly, also Mn,Na_2,K_2,H_2. Further often containing aluminium and ferric iron, in part with alkalies as $NaAl(SiO_3)_2$ or $NaFe(SiO_3)_2$; perhaps also containing $\overset{II}{R}\overset{III}{R}_2SiO_6$.

α. Orthorhombic Section

		a : *b*
Anthophyllite	$(Mg,Fe)SiO_3$	0·5138 : 1
GEDRITE	$(Mg,Fe)SiO_3$ with $(Mg,Fe)Al_2SiO_6$	

β. Monoclinic Section

	a : *b* : *c*	*β*
Amphibole	0·5511 : 1 : 0·2938	73° 58′

I. *NONALUMINOUS VARIETIES.*

1. TREMOLITE	$CaMg_3(SiO_3)_4$
2. ACTINOLITE	$Ca(Mg,Fe)_3(SiO_3)_4$
Nephrite, Asbestus,	Smaragdite, etc.
Cummingtonite	$(Fe,Mg)SiO_3$
Dannemorite	$(Fe,Mn,Mg)SiO_3$
Grünerite	$FeSiO_3$
3. RICHTERITE	$(K_2,Na_2,Mg,Ca,Mn)_4(SiO_3)_4$

II. *ALUMINOUS VARIETIES.*

4. HORNBLENDE	
Edenite Pargasite and Common Hornblende	Chiefly $Ca(Mg,Fe)_3(SiO_3)_4$ with $Na_2Al_2(SiO_3)_4$ and $(Mg,Fe)_2(Al,Fe)_4Si_2O_{12}$

		$a : b : c$	β
Glaucophane	$NaAl(SiO_3)_2.(Fe,Mg)SiO_3$		
Riebeckite	$2NaFe(SiO_3)_2.FeSiO_3$	0·5475 : 1 : 0·2925	= 76° 10′
Crocidolite	$NaFe(SiO_3)_2.FeSiO_3$		
Arfvedsonite	$Na_6(Ca,Mg)_3(Fe,Mn)_{14}(Al,Fe)_2Si_{21}O_{45}$	0·5509 : 1 : 0·2378	= 73° 2′

γ. Triclinic Section

Ænigmatite.

The only species included under the triclinic section is the rare and imperfectly known ænigmatite (cossyrite).

The Amphibole Group embraces a number of species which, while falling in different systems, are yet closely related in form — as shown in the common prismatic cleavage of 54° to 56° — also in optical characters and chemical composition. As already noted (see p. 471), the species of this group form chemically a series parallel to that of the closely allied Pyroxene Group, and between them there is a close relationship in crystalline form and other characters. The Amphibole Group, however, is less fully developed, including fewer species, and those known show less variety in form.

The chief *distinctions* between pyroxene and amphibole proper are the following:

Prismatic angle with pyroxene 87° and 93°; with amphibole 56° and 124°; the prismatic cleavage being much more distinct in the latter.

With pyroxene, crystals usually short prismatic and often complex, structure of massive kinds mostly lamellar or granular; with amphibole, crystals chiefly long prismatic and simple, columnar and fibrous massive kinds the rule.

The specific gravity of most of the pyroxene varieties is higher than of the like varieties of amphibole. In composition of corresponding kinds, magnesium is present in larger amount in amphibole (Ca : Mg = 1 : 1 in diopside, = 1 : 3 in tremolite); alkalies more frequently play a prominent part in amphibole.

The optical relations of the prominent members of the group, as regards the position of the ether-axes, is exhibited by the following figures (Cross); compare Fig. 797, p. 472, for a similar representation for the corresponding members of the pyroxene group.

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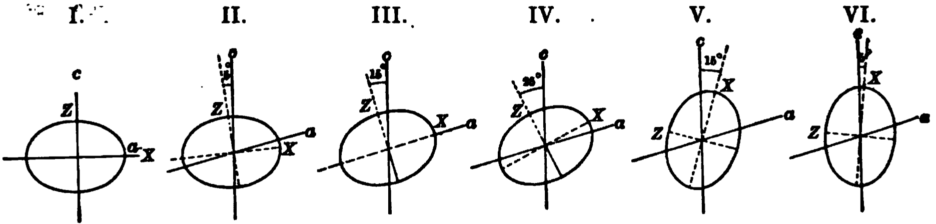

I. Anthophyllite. II. Glaucophane. III. Tremolite, etc. IV. Hornblende. V. Arfvedsonite. VI. Riebeckite.

α. Orthorhombic Section

ANTHOPHYLLITE.

Orthorhombic. Axial ratio $a : b$ = 0·5137 : 1. Crystals rare, habit prismatic (mm''' 110 ∧ 1$\bar{1}$0 = 54° 23). Commonly lamellar, or fibrous massive; fibres often very slender; in aggregations of prisms.

Cleavage: prismatic, perfect; *b* (010) less so; *a* (100) sometimes distinct. H. = 5·5–6. G. = 3·1–3·2. Luster vitreous, somewhat pearly on the cleavage face. Color brownish gray, yellowish brown, clove-brown, brownish green, emerald-green, sometimes metalloidal. Streak uncolored or grayish. Transparent to subtranslucent. Sometimes pleochroic Usually optically +; also + for red, − for yellow, green. Ax. pl. always $\parallel$ *b* (010). Bx$_a$ usually $\perp$ *c* (001); also $\perp$ *c* (001) for red, $\perp$ *a* (100) for yellow, green. 2 V = 84°. α = 1·633. β = 1·642. γ = 1·657.

Comp. — (Mg,Fe)SiO$_3$, corresponding to enstatite-bronzite-hypersthene in the pyroxene group. Aluminium is sometimes present in considerable amount. There is the same relation in optical character between anthophyllite (+) and gedrite (−) as between enstatite and hypersthene (cf. Figs. 799 800, p. 472).

Var. — Anthophyllite, Mg : Fe = 4 : 1, 3 : 1, etc. For 3 : 1, the percentage composition is: Silica 55·6, iron protoxide 16·6, magnesia 27·8 = 100. Anthophyllite sometimes occurs in forms resembling asbestus.

Aluminous, Gedrite. Iron is present in larger amount, and also aluminium; it hence corresponds nearly to a hypersthene, some varieties of which are highly aluminous.

Ferroanthophyllite is a name given to an iron anthophyllite from Idaho and elsewhere.

Hydrous anthophyllites have been repeatedly described, but in most cases they have been shown to be hydrated monoclinic amphiboles.

Pyr., etc. — B.B. fuses with difficulty to a black magnetic enamel; with the fluxes gives reactions for iron; unacted upon by acids.

Micro. — In sections colorless, non-pleochroic. Parallel extinction. Commonly fibrous.

Artif. — Anthophyllite is formed artificially when magnesium metasilicate is heated considerably above its melting point and then quickly cooled.

Obs. — Anthophyllite occurs in mica schist near Kongsberg in Norway; at Hermannschlag, Moravia. In the United States, at the Jenks corundum mine, Franklin, Macon Co., N. C.; from Rockport, Mass. A colorless or pale red variety from Edwards, N. Y., has been called *valléite*. The original *gedrite* is from the valley of Héas, near Gedres, France. Named from *anthophyllum*, *clove*, in allusion to the clove-brown color.

β. Monoclinic Section

AMPHIBOLE. Hornblende.

Monoclinic. Axes $a : b : c = 0·5511 : 1 : 0·2938$; $\beta = 73° 58'$.

mm''', $110 \wedge 1\bar{1}0 = 55° 49'$. *rr'*, $011 \wedge 0\bar{1}1 = 31° 32'$.
ca, $001 \wedge 100 = 73° 58'$. *ii*, $031 \wedge 0\bar{3}1 = 80° 32'$.
cp, $001 \wedge \bar{1}01 = 31° 0'$. *pr*, $\bar{1}01 \wedge 011 = 34° 25'$.

Twins: (1) tw. pl. *a* (100), common as contact-twins; rarely polysynthetic. (2) *c* (001), as tw. lamellæ, occasionally producing a parting analogous to that more common with pyroxene (Fig. 461, p. 173). Crystals commonly

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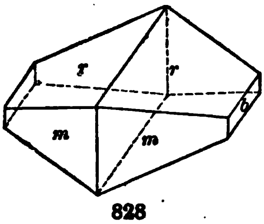

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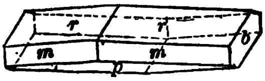

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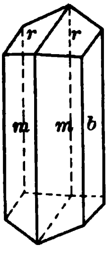

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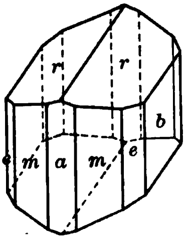

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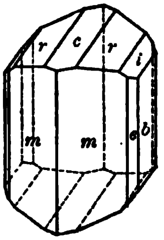

prismatic; usually terminated by the low clinodome, *r* (011), sometimes by *r* and *p* ($\bar{1}$01) equally developed and then suggesting rhombohedral forms (as of tourmaline). Also columnar or fibrous, coarse or fine, fibres often like flax; rarely lamellar; also granular massive, coarse or fine, and usually strongly coherent, but sometimes friable.

Cleavage: *m* (110) highly perfect; *a* (100), *b* (010) sometimes distinct. Fracture subconchoidal, uneven. Brittle. H. = 5–6. G. = 2·9–3·4, varying with the composition. Luster vitreous to pearly on cleavage faces; fibrous varieties often silky. Color between black and white, through various shades of green, inclining to blackish green; also dark brown; rarely yellow, pink, rose-red. Streak uncolored, or paler than color. Sometimes nearly transparent; usually subtranslucent to opaque.

Pleochroism strongly marked in all the deeply colored varieties, as described beyond. Absorption usually $Z > Y > X$. Optically –, rarely +. Ax. pl. $\parallel$ *b* (010). Extinction-angle on *b* (010), or $Z \wedge c$ axis = + 15° to 18° in most cases, but varying from about 1° up to 37°; hence also $Bx_a \wedge c$ axis = – 75° to – 72°, etc. See Fig. 832. Dispersion $\rho < v$. Axial angles variable; see beyond.

Optical characters, particularly indices of refraction, birefringence and extinction angles vary with change in composition, particularly with the total amount of iron present. In general the indices and extinction angles increase with increase of iron content while the birefringence decreases.

Comp. — In part a normal metasilicate of calcium and magnesium, $RSiO_3$, usually with iron, also manganese, and thus in general analogous to the pyroxenes. The alkali metals, sodium and potassium, also present, and more commonly so than with pyroxene. In part also aluminous, corresponding to the aluminous pyroxenes. Titanium sometimes is present and also rarely fluorine in small amount.

The aluminium is in part present as $NaAl(SiO_3)_2$, but many amphiboles containing aluminium or ferric iron are more basic than a normal metasilicate; they may sometimes be explained as containing $\overset{II}{R}\overset{III}{(Al,Fe)}_2SiO_6$, but the exact nature of the compound is often doubtful. The amphibole formulas are in many cases double the corresponding ones for pyroxene. Thus, for most tremolite and actinolite, Ca : Mg(Fe) = 1 : 3, and hence tremolite is $CaMg_3Si_4O_{12}$, while diopside is $CaMgSi_2O_6$, etc.

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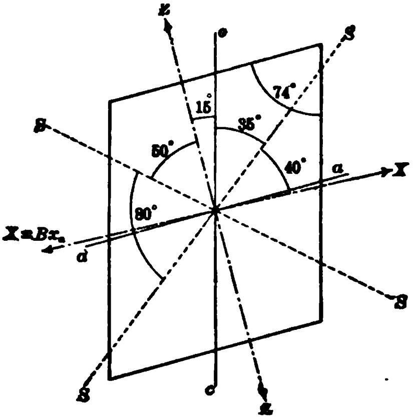

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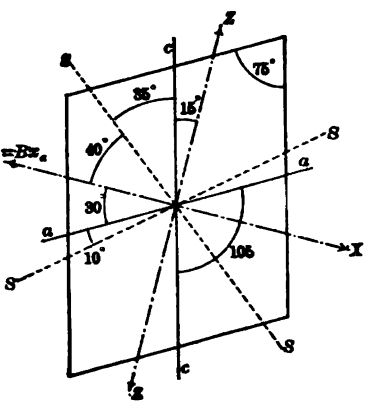


Rammelsberg has shown that the composition of most aluminous amphiboles may be expressed in the general form $m\mathrm{RSiO_3}.n\mathrm{Al_2O_3}$; while Scharizer, modifying this view, proposes to regard the amphiboles as molecular compounds of $Ca(Mg,Fe)_3Si_4O_{12}$ (actinolite), and the orthosilicate $(\overset{I}{R}_2,\overset{II}{R})_3\overset{III}{R}_2Si_3O_{12}$, for which he uses Breithaupt's name *syntagmatite*, originally given to the Vesuvian hornblende.

Penfield concludes that (1) amphibole is a metasilicate, (2) that fluorine and hydroxyl are isomorphous with the protoxides and (3) that the presence of sesquioxides is explained by their introduction into the molecule in the form of various bivalent radicals.

The crystallographic position here adopted is that suggested by Tschermak, which best exhibits the relation between amphibole and pyroxeme. Some authors retain the former position, according to which $p = (001)$, $r = (\bar{1}11)$, etc. Fig. 833 shows the corresponding optical orientation.

I. *Containing little or no Aluminium*

1. **Tremolite.** Grammatite, nephrite in part. *Calcium-magnesium amphibole.* Formula $CaMg_3(SiO_3)_4$ = Silica 57·7, magnesia 28·9, lime 13·4 = 100. Ferrous iron, replacing the magnesium, present only sparingly, up to 3 p. c. Colors white to dark gray. In distinct crystals, either long-bladed or short and stout. In aggregates long and thin columnar, or fibrous; also compact granular massive (nephrite, below). G. = 2·9–3·1. Sometimes transparent and colorless. Optically −. Extinction-angle on *b* (010), or $Z \wedge c$ axis = +16° to 18°, hence $Bx_a \wedge c$ axis = − 74° to − 72°. 2V = 80° to 88°. $\alpha = 1{\cdot}609$. $\beta = 1{\cdot}623$. $\gamma = 1{\cdot}635$.

Tremolite was named by Pini from the Tremola valley on the south side of the St. Gothard.

Winchite is the name given to a blue amphibole near tremolite from the manganese mines of Central India.

2. **Actinolite.** *Calcium-magnesium-iron amphibole.* Formula $Ca(Mg,Fe)_3(SiO_3)_4$. Color bright green and grayish green. In crystals, either short- or long-bladed, as in tremolite; columnar or fibrous; granular massive. G. = 3–3·2. Sometimes transparent. The variety in long bright-green crystals is called *glassy actinolite;* the crystals break easily across the prism. The fibrous and radiated kinds are often called *asbestiform actinolite and radiated actinolite.* Actinolite owes its green color to the ferrous iron present.

Pleochroism distinct, increasing as the amount of iron increases, and hence the color becomes darker; *Z* emerald-green, *Y* yellow-green, *X* greenish yellow. Absorption $Z > Y > X$, Zillertal. Optically −. Extinction-angle on *b* (010), $Z \wedge c$ axis = + 15° and $Bx_a \wedge c$ axis = − 75°. 2V = 78°; $\rho < v$; $\alpha = 1{\cdot}611$. $\beta = 1{\cdot}627$. $\gamma = 1{\cdot}636$.

Named actinolite from ἀκτίς, *a ray*, and λίθος, *stone*, a translation of the German *Strahlstein* or *radiated stone*. Name changed to *actinote* by Haüy, without reason.

Nephrite. Jade in part. A tough, compact, fine-grained tremolite (or actinolite). breaking with a splintery fracture and glistening luster. H. = 6–6·5. G. = 2·96–3·1. Named from a supposed efficacy in diseases of the kidney, from νεφρός, *kidney*. It varies in color from white (tremolite) to dark green (actinolite), in the latter, iron protoxide being present up to 6 or 7 p. c. The latter kind sometimes encloses distinct prismatic crystals of actinolite. A derivation from an original pyroxenic mineral has been suggested in some cases. Nephrite or jade was brought in the form of carved ornaments from Mexico or Peru soon after the discovery of America. A similar stone comes from Eastern Asia, New Zealand and Alaska. See jadeite, p. 481; jade, p. 482.

Széchenyiite is an amphibole occurring with jadeite from Central Asia.

Asbestus. Asbestos. Tremolite, actinolite, and other varieties of amphibole, excepting those containing much alumina, pass into fibrous varieties, the fibers of which are sometimes very long, fine, flexible, and easily separable by the fingers, and look like flax. These kinds are called *asbestus* (from the Greek for *incombustible*). The colors vary from white to green and wood-brown. The name *amianthus* is applied usually to the finer and more silky kinds. Much that is popularly called asbestus is *chrysotile*, or fibrous serpentine, containing 12 to 14 p. c. of water. *Byssolite* is a stiff fibrous variety.

Mountain leather is in thin flexible sheets, made of interlaced fibers; and *mountain cork* the same in thicker pieces; both are so light as to float on water, and they are often hydrous, color white to gray or yellowish. *Mountain wood* is compact fibrous, and gray to brown in color, looking a little like dry wood.

SMARAGDITE. A thin-foliated variety of amphibole, near actinolite in composition but carrying some alumina. It has a light grass-green color, resembling much common green diallage. In many cases derived from pyroxene (diallage) by uralitization, see below. It retains much of the structure of the diallage and also often encloses remnants of the original mineral. It forms, along with whitish or greenish saussurite, a rock called saussurite-gabbro, the euphotide of the Alps. The original mineral is from Corsica, and the rock is the *verde di Corsica duro* of the arts.

URALITE. Pyroxene altered to amphibole. The crystals, when distinct, retain the form of the original mineral, but have the cleavage of amphibole. The change usually commences on the surface, transforming the outer layer into an aggregation of slender amphibole prisms, parallel in position to each other and to the parent pyroxene (cf. Fig. 803, p. 473). When the change is complete the entire crystal is made up of a bundle of amphibole needles or fibers. The color varies from white (tremolite) to pale or deep green, the latter the more common. In composition uralite appears to conform nearly to actinolite, as also in optical characters. The most prominent change in composition in passing from the original pyroxene is that corresponding to the difference existing between the two species in general, that is, an increase in the magnesium and decrease in calcium. The change, therefore, is not strictly a case of paramorphism, although usually so designated. Uralite was originally described by Rose in a rock from the Ural Mts. It has since been observed from many localities. The microscopic study of rocks has shown the process of "uralitization" to be very common, and some authors regard many hornblendic rocks and schists to represent altered pyroxenic rocks on a large scale.

CUMMINGTONITE. Amphibole-Anthophyllite. *Iron-Magnesium Amphibole.* Here belong certain varieties of amphibole resembling anthophyllite and essentially identical with it in composition, but optically monoclinic. From Kongsberg, Norway; Greenland. The original *cummingtonite* is gray to brown in color; usually fibrous or fibro-lamellar, often radiated. G. = 3·1–3·32; from Cummington, Mass.

DANNEMORITE. *Iron-Manganese Amphibole.* Color yellowish brown to greenish gray. Columnar or fibrous, like tremolite and asbestus. Contains iron and manganese. From Sweden. *Juddite* is a manganese amphibole found at Kácharwáhi, India.

GRÜNERITE. *Iron-Amphibole.* Asbestiform or lamellar-fibrous. Luster silky; color brown; G. = 3·713. Formula $FeSiO_3$.

3. RICHTERITE. *Sodium-Magnesium-Manganese Amphibole.* $(K_2,Na_2,Mg,Ca,Mn)_4(SiO_3)_4$.

In elongated crystals, seldom terminated. G. = 3·09. Color brown, yellow, rose-red. Transparent to translucent. $Z \wedge c$ axis = + 17°–20°; $\beta = 1{\cdot}63$; $\gamma - \alpha = 0{\cdot}024$. From Pajsberg and Långban, Sweden. Characterized by the presence of manganese and alkalies in relatively large amount.

Imerinite is a soda-amphibole, related to soda-richterite from the province Imerina, Madagascar.

Breislakite occurs in wool-like forms at Vesuvius and Capo di Bove, Italy. Color dark brown to black, pleochroism strongly marked. Inferred to belong near richterite.

II. *Aluminous.*

4. ALUMINOUS AMPHIBOLE. Hornblende. Contains alumina or ferric iron, and usually both, with ferrous iron (sometimes manganese), magnesium, calcium, and alkalies. The kinds here included range from the light-colored *edenite*, containing but little iron, through the light to dark green *pargasite*, to the dark-colored or black *hornblende*, the color growing darker with increase in amount of iron. Extinction-angle variable, from 0° to 37°, see below. Pleochroism strong. Absorption usually $Z < Y < X$.

EDENITE. *Aluminous Magnesium-Calcium Amphibole.* Color white to gray and pale green, and also colorless; G. = 3·0–3·059. Resembles anthophyllite and tremolite. Named from the locality at Edenville, N. Y. To this variety belong various pale-colored amphiboles, having less than 5 p. c. of iron oxides.

Koksharovite is a variety from the neighborhood of Lake Baikal, Siberia, named after the Russian mineralogist, von Koksharov.

Soretite is an aluminous amphibole from the anorthite-diorite rocks of Koswinsky in the northern Ural Mts.

COMMON HORNBLENDE, PARGASITE. Colors bright or dark green, and bluish green to grayish black and black. G. = 3·05–3·47. *Pargasite* is usually made to include green and bluish green kinds, occurring in stout lustrous crystals, or granular; and *Common hornblende* the greenish black and black kinds, whether in stout crystals or long-bladed, columnar, fibrous, or massive granular. But no line can be drawn between them. The extinction-angle on *b* (010), or $Z \wedge c$ axis = + 15° to 25° chiefly. Absorption $Z > Y > X$.

Pargasite occurs at Pargas, Finland, in bluish green and grayish black crystals. $Z \wedge c$ axis = + 18°; $\beta = 1{\cdot}64$; $\gamma - \alpha = 0{\cdot}019$; 2V = 59°. Pleochroism: Z greenish blue; Y emerald-green; X greenish yellow.

The dark brown to black *hornblendes* from basaltic and other igneous rocks vary somewhat widely in optical characters. The angle $Z \wedge c$ axis = 0° to + 10° chiefly; $\beta = 1{\cdot}725$; $\gamma - \alpha = 0{\cdot}072$ (maximum). Pleochroism: Z brown, Y yellow, X yellow-green, but variable.

Speziaite, from Traversella, Italy, is an iron amphibole with strong pleochroism; X = green, Y = yellow-brown, Z = azure-blue, $Z \wedge c$ axis = 23°.

The *Kataforite* of Norway (Brögger) has $Z \wedge c$ axis = 30° to 60°; absorption $Y > Z > X$; pleochroism: Z yellow, Z violet, X yellow-brown; it approximates toward arfvedsonite (p. 494).

Kupfferite, from a graphite mine in the Tunkinsk Mts., near Lake Baikal, Siberia, is a deep green amphibole (aluminous) formerly referred to anthophyllite.

Syntagmatite is the black hornblende of Vesuvius.

Bergamaskite is an iron-amphibole containing almost no magnesia. From Monte Altino, Province of Bergamo, Italy.

Kaersutite is a titaniferous amphibole from Kaersut, Umanaks fiord, North Greenland.

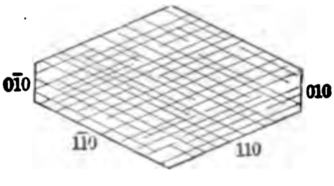
Hastingsite is an amphibole low in silica and high in iron and soda, from the nephelite-syenite of Dungannon, Hastings Co., Ontario.

Philipstadite from Philipstad, Sweden, is an iron-magnesium amphibole showing unusual pleochroism.

Pyr. — Essentially the same as for the corresponding varieties of pyroxene, see p. 478.

Diff. — Distinguished from pyroxene (and tourmaline) by its distinct prismatic cleavage, yielding angles of 56° and 124°. Fibrous and columnar forms are much more common than with pyroxene, lamellar and foliated forms rare (see also pp. 478, 486). Crystals often long, slender, or bladed. Differs from the fibrous zeolites in not gelatinizing with acids. Epidote has a peculiar green color, is more fusible, and shows a different cleavage.

834



Micro. — In rock sections amphibole generally shows distinct colors, green, sometimes olive or brown, and is strongly pleochroic. Also recognized by its high relief; generally rather high interference-colors; by the very perfect system of cleavage-cracks crossing at angles of 56° and 124° in sections ⊥ *c* axis (Fig. 834). In sections ∥ *b* (010) (recognized by yielding no axial figure in convergent light, by showing the highest interference-colors, and by having parallel cleavage-cracks, ∥ *c* axis), the extinction-direction for common hornblendes makes a small angle (12°–15°) with the cleavage-cracks (*i.e.*, with *c* axis); further, this direction is positive Z (different from common pyroxene and ægirite, cf. Figs. 813 and 818).

Artif. — Experiments on the artificial production of the amphiboles have shown that in general they are unstable at high temperatures and that their formation in igneous rocks is due either to the rapid cooling of the magma, to the presence of water or to some unusual conditions of pressure, etc. In general when the amphiboles are fused they are transformed into the corresponding pyroxenes.

Obs. — Amphibole occurs only sparingly in volcanic rocks but is found in many crystalline limestones, and granitic and schistose rocks. *Tremolite*, the magnesia-lime variety, is especially common in limestones, particularly magnesian or dolomitic; *actinolite* (also nephrite), the magnesia-lime-iron variety, in the crystal line schists, in steatitic rocks and with serpentine; and dark green and black *hornblende*, occurs in both igneous and metamorphic rocks. It is found in granites, syenites, diorites and some varieties of peridotite, in gneisses and the hornblende schists.

Hornblende-rock, or *amphibolite*, consists of massive hornblende of a dark greenish black or black color, and has a granular texture. Occasionally the *green* hornblende, or actinolite, occurs in rock-masses, as at St. Francis, in Canada. *Hornblende-schist* has the same composition as amphibolite, but is schistose or slaty in structure. It often contains a little feldspar. In some varieties of it the hornblende is in part in minute needles. Granite and syenite often contain hornblende, and with diorite it is a common constituent. This is also true of the corresponding forms of gneiss. In these cases it is usually present in small, irregular masses, often fibrous in structure; also as rough bladed crystals.

Prominent foreign localities of amphibole are the following: *Tremolite* (grammatite) in dolomite at Campolongo, Switzerland; also at Orawitza, Rezbánya, Hungary; Gulsjö, Wermland, Sweden. *Actinolite* in the crystalline schists of the Central and Eastern Alps, especially at Greiner in the Zillertal, Tyrol; at Zöblitz in Saxony; Arendal, Norway. *Asbestus* at Sterzing, Zillertal, and elsewhere in Tyrol; in Savoie, France; also in the island of Corsica. *Pargasite* at Pargas, Finland; Saualpe in Carinthia. *Hornblende* at Arendal, Kongsberg and Kargerö, Norway; in Sweden and Finland; at Vesuvius; Aussig and Teplitz, Bohemia; etc. *Nephrite*, which in the form of "jade" ornaments and utensils is widely distributed among the relics of early man (see jade, p. 482), is obtained at various points in Central Asia. The most important source is that in the Karakash valley in the Kuen Lun Mts., on the southern borders of Turkestan; also other localities in Central Asia. In New Zealand. Nephrite has been found in Europe as a rolled mass at Schwemmsal near Leipzig; in Swiss Lake habitations and similarly elsewhere.

In the United States, in Me., black crystals occur at Thomaston; pargasite at Phippsburg. In Ver., actinolite in the steatite quarries of Windham and New Fane. In Mass., tremolite at Lee; black crystals at Chester; asbestus at Pelham; *cummingtonite* at Cummington. In Conn., in large flattened white crystals and in bladed and fibrous forms (tremolite) in dolomite, at Canaan. In N. Y., Warwick, Orange Co.; near Edenville; near Amity; at the Stirling mines, Orange Co.; in short green crystals at Gouverneur, St. Lawrence Co.; with pyroxene at Russell; a black variety at Pierrepont; at Macomb; Pitcairn; tremolite at Fine; in Rossie, 2 miles north of Oxbow; in large white crystals at Diana, Lewis Co.; asbestus near Greenwood Furnace. *Hudsonite* from Cornwall, N. Y., formerly classed as a pyroxene has been shown to be an amphibole. In N. J., tremolite or gray amphibole in good crystals at Bryam, and other varieties of the species at Franklin and Newton, radiated actinolite. In Pa., actinolite at Mineral Hill, in Delaware Co.; at Unionville; at Kennett, Chester Co. In Md., actinolite and asbestus at the Bare Hills in serpentine; asbestus is mined at Pylesville, Harford Co. In Va., actinolite at Willis's Mt., in Buckingham Co.; asbestus at Barnet's Mills, Fauquier Co. Nephrite occurs in Alaska.

In Canada, tremolite is abundant in the Laurentian limestones, at Calumet Falls, Litchfield, Pontiac Co., Quebec; also at Blythfield, Renfrew Co., and Dalhousie, Lanark Co. Black hornblende at various localities in Quebec and Ontario with pyroxene, apatite, titanite, etc., as in Renfrew Co. Asbestus and mountain cork at Buckingham, Ottawa Co., Quebec; a bed of actinolite at St. Francis, Beauce Co., Quebec; nephrite has been found in British Columbia and Northwest Territory.

GLAUCOPHANE.

Monoclinic; near amphibole in form. Crystals prismatic in habit, usually indistinct; commonly massive, fibrous, or columnar to granular.

Cleavage: *m* (110) perfect. Fracture conchoidal to uneven. Brittle. H. = 6–6·5. G. = 3·103–3·113. Luster vitreous to pearly. Color azure-blue, lavender-blue, bluish black, grayish. Streak grayish blue. Translucent. Pleochroism strongly marked: Z sky-blue to ultramarine-blue, Y reddish or bluish violet, X yellowish green to colorless. Absorption $Z > Y > X$. Optically +. Ax. pl. $\parallel b$ (010). $Z \wedge c$ axis = 4° to 6°, rarely higher values. $2V = 45°$. $\alpha = 1{\cdot}621$. $\beta = 1{\cdot}638$. $\gamma = 1{\cdot}638$.

Comp. — Essentially $NaAl(SiO_3)_2.(Fe,Mg)SiO_3$. If Mg : Fe = 2 : 1, the formula requires: Silica 57·6, alumina 16·3, iron protoxide 7·7, magnesia 8·5, soda 9·9 = 100.

Obs. — Occurs as the hornblendic constituent of certain crystalline schists, called *glaucophane-schists*, or glaucophanite; also more or less prominent in mica schists, amphibolites, gneiss, eclogites, etc. It is often associated with mica, garnet, diallage and omphacite, epidote and zoisite, etc. First described from the island of Syra, one of the Cyclades; since shown to be rather widely distributed, as on the southern slope of the Alps (*gastaldite*), Corsica, Japan, etc. *Rhodusite* is a fibrous variety from the Island Rhodus and Asskys river, Minassinsk, Siberia. *Holmquistite* is a lithium-bearing variety from the Island of Utö.

In the United States, glaucophane schists have been described from the Coast Ranges of California, as at Sulphur Bank, Lake Co.

Glaucophane is named from γλαυκός, *bluish green*, and φαίνεσθαι, *to appear.*

Crossite. An amphibole intermediate in composition between glaucophane and riebeckite, being optically more nearly related to the latter. Occurs in lath shaped crystals. Color blue. Strongly pleochroic. Found in the crystalline schists of the Coast Ranges of California.

RIEBECKITE.

Monoclinic. Axes $a : b : c = 0{\cdot}5475 : 1 : 0{\cdot}2925$; $\beta = 76° 10'$. In embedded prismatic crystals, longitudinally striated. Cleavage: prismatic (56°) perfect. Luster vitreous. Color black. Pleochroism very strongly marked: Z green, Y (= b axis) deep blue, X (nearly $\parallel$ c axis) dark blue. Optically −. Extinction-angle small, $X \wedge c$ axis = 4°–5° (±?). Axial angle large. $\beta = 1{\cdot}687$.

Comp. — Essentially $2\text{Na}\overset{\text{III}}{\text{Fe}}(\text{SiO}_3)_2.\text{FeSiO}_3$ = Silica 50·5, iron sesquioxide 26·9, iron protoxide 12·1, soda 10·5 = 100. It corresponds closely to acmite (ægirite) among the pyroxenes.

Obs. — Originally described from the granite and syenite of the island of Socotra in the Indian Ocean, 120 m. N. E. of Cape Guardafui, the eastern extremity of Africa; occurs in groups of prismatic crystals, often radiating and closely resembling tourmaline; also in granophyre blocks found at Ailsa Crag and at other points in Scotland and Ireland. A similar amphihole occurs at Mynydd Mawr, Carnarvonshire, Wales. Also another in granulite in Corsica. Found at Narsarsuk, Greenland. From pegmatite at Quincy, Mass. A so-called arfvedsonite from St. Peter's Dome, Pike's Peak region, Col., occurring with astrophyllite and zircon, is shown by Lacroix to be near riebeckite. Extinction-angle on b, $X \wedge c$ axis = 3° to 4°. A soda amphibole, related to riebeckite, from Bababudan Hills, Mysore, India, has been named *bababudanite.*

CROCIDOLITE. Blue Asbestus.

Fibrous, asbestus-like; fibers long but delicate, and easily separable. Also massive or earthy. Cleavage: prismatic, 56°. H. = 4. G. = 3·20–3·30. Luster silky; dull. Color and streak lavender-blue or leek-green. Opaque. Fibers somewhat elastic. Pleochroism: Z green, Y violet, X blue. Optically +. Extinction-angle on b (010) inclined 18° to 20° with c axis. 2E = 95° approx. $\gamma - \alpha = 0{\cdot}025$.

Comp. — $\text{Na}\overset{\text{III}}{\text{Fe}}(\text{SiO}_3)_2.\text{FeSiO}_3$ (nearly) = Silica 49·6, iron sesquioxide 22·0, iron protoxide 19·8, soda 8·6 = 100.

Magnesium and calcium replace part of the ferrous iron, and hydrogen part of the sodium.

Pyr., etc. — B.B. fuses easily with intumescence to a black magnetic glass, coloring the flame yellow (soda). With the fluxes gives reactions for iron. Unacted upon by acids.

Obs. — Occurs in South Africa, in Griqualand-West, north of the Orange river, in a range of quartzose schists called the Asbestos Mountains. In a micaceous porphyry near Framont, in the Vosges Mts. At Golling in Salzburg, Austria. In the United States, at Beacon Pole Hill, near Cumberland, R. I. Emerald Mine, Buckingham, and Perkin's Mill, Templeton, Ottawa Co., Ontario, Canada.

Abriachanite is an earthy amorphous form occurring in the Abriachan district, near Loch Ness, Scotland. Crocidolite is named from κροκίς, *woof*, in allusion to its fibrous structure.

The South African mineral is largely altered by both oxidation of the iron and infiltration of silica, resulting in a compact siliceous stone of delicate fibrous structure, chatoyant luster, and bright yellow to brown color, popularly called *tiger-eye* (also cat's-eye). Many varieties occur forming transitions from the original blue mineral to the final product; also varieties depending upon the extent to which the original mineral has penetrated the quartz.

ARFVEDSONITE.

Monoclinic. Axes $a : b : c = 0·5569 : 1 : 0·2978$; $\beta = 73° 2'$.

Crystals long prisms, often tabular || b (010), but seldom distinctly terminated; angles near those of amphibole; also in prismatic aggregates. Twins: tw. pl. a (100).

Cleavage: prismatic, perfect; b (010) less perfect. Fracture uneven. Brittle. H. = 6. G. = 3·44–3·45 Luster vitreous. Color pure black; in thin scales deep green. Streak deep bluish gray. Opaque except in thin splinters. Pleochroism strongly marked: Z deep greenish blue, Y lavender, X pale greenish yellow. Absorption $Z > Y > X$; sections || a (100) are deep greenish blue, || b (010) olive-green. Optically –. Axial angle, large. $\alpha = 1·687$. $\beta = 1·707$. $\gamma = 1·708$. Extinction-angle on b (010), with c axis = 14°.

Comp. — A slightly basic metasilicate of sodium, calcium, and ferrous iron chiefly.

The supposed arfvedsonite from Greenland has been shown to be ægirite; that from Pike's Peak, Col., has been referred to riebeckite.

Pyr., etc. — B.B. fuses at 2 with intumescence to a black magnetic globule; colors the flame yellow (soda); with the fluxes gives reactions for iron and manganese. Not acted upon by acids.

Micro. — In thin sections shows brown- or gray-green or gray-violet colors; strongly pleochroic in blue and green tints; negative elongation.

Obs. — Arfvedsonite and amphiboles of similar character, containing much iron and soda, are constituents of certain igneous rocks which are rich in alkalies, as nephelite-syenite, certain porphyries, etc. Large and distinct crystals are found only in the pegmatite veins in such rocks, as at Kangerdluarsuk, Narsarsuk, Greenland, where the associated minerals are sodalite, eudialyte, feldspar, etc. Arfvedsonite occurs also in the nephelite-syenites and related rocks of the Christiania region in southern Norway; on the Kola peninsula in Russian Lapland; Dungannon township, Ontario; Trans Pecos district, Texas. The related brownish pleochroic amphiboles (cf. barkevikite) occur in similar rocks at Montreal, Canada; Red Hill, N. H.; Salem, Mass.; Magnet Cove, Ark.; Black Hills, S. D.; Square Butte, Mon. St. Peter's Dome, Col., etc.

Osannite from an amphibole-gneiss at Cevadaes, Portugal, and *Tschernichéwite* from a magnetite bearing quartzite in the northern Ural Mts., are near arfvedsonite.

Barkevikite. An amphibole near arfvedsonite but more basic. In prismatic crystals. Cleavage: prismatic (55° 44½'). G. = 3·428. Color deep velvet-black. Pleochroism marked, colors brownish. Extinction-angle with c axis on b (010) = 12½°. Occurs at the wöhlerite locality near Barkevik, on the Langesund fiord, and elsewhere in southern Norway. In large crystals at Lugar, Ayrshire, Scotland.

Ænigmatite. Cossyrite. Essentially a titano-silicate of ferrous iron and sodium, but containing also aluminium and ferric iron. In prismatic triclinic crystals. Cleavage: prismatic, distinct (66°). G. = 3·74–3·80. Color black. Ænigmatite is from the sodalite-syenite of Tunugdliarfik and Kangerdluarsuk, Greenland. *Cossyrite* occurs in minute crystals embedded in the liparite lavas of the island Pantellaria (ancient name Cossyra); also widespread in the rocks of East Africa. *Rhönite* is like ænigmatite but contains much less ferrous oxide and alkalies with increase in alumina, ferric oxide, etc. From basaltic rocks in the Rhön district and elsewhere in Germany and Bohemia.

Weinbergerite. Perhaps $NaAlSiO_4.3FeSiO_3$. Orthorhombic. In spherical aggregates of radiating fibers. Black color. From a meteoric iron at Codai Canal, Palni Hills, Madras, India.

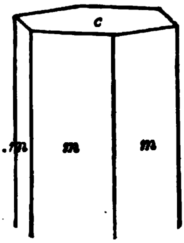
BERYL.

Hexagonal. Axis $c = 0{\cdot}4989$.

Crystals usually long prismatic, often striated vertically, rarely transversely; distinct terminations exceptional. Occasionally in large masses, coarse columnar or granular to compact.

Cleavage: c (0001), imperfect and indistinct. Fracture conchoidal to uneven. Brittle. H. = 7·5–8. G. = 2·63–2·80; usually 2·69–2·70. Luster vitreous, sometimes resinous. Colors emerald-green, pale green, passing into light blue, yellow and white; also pale rose-red. Streak white. Transparent to subtranslucent. Dichroism more or less distinct. Optically −. Birefringence low. Often abnormally biaxial. $\omega = 1{\cdot}5820$, $\epsilon = 1{\cdot}5765$, aquamarine.

835



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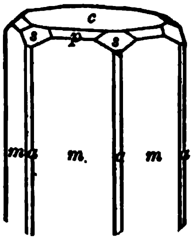

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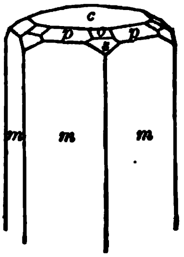

cp, $0001 \wedge 10\bar{1}1 = 29° \, 56\tfrac{1}{2}'$. cs, $0001 \wedge 11\bar{2}1 = 44° \, 56'$.
co, $0001 \wedge 11\bar{2}2 = 26° \, 31'$. pp', $10\bar{1}1 \wedge 01\bar{1}1 = 28° \, 54\tfrac{1}{2}'$.

Var. — 1. *Emerald.* Color bright emerald-green, due to the presence of a little chromium; highly prized as a gem when clear and free from flaws.

2. *Ordinary; Beryl.* Generally in hexagonal prisms, often coarse and large; green the common color. The principal kinds are : (*a*) colorless; (*b*) bluish green, called *aquamarine;* (*c*) apple-green; (*d*) greenish yellow to iron-yellow and honey-yellow; sometimes a clear bright yellow as in the *golden beryl* (a yellow gem variety from Southwest Africa has been called *heliodor*); (*e*) pale yellowish green; (*f*) clear sapphire blue; (*g*) pale sky-blue; (*h*) pale violet or reddish; (*i*) rose colored called *morganite* or *vorobyevite;* (*j*) opaque brownish yellow, of waxy or greasy luster. The *oriental emerald* of jewelry is emerald-colored sapphire.

Comp. — $Be_3Al_2(SiO_3)_6$ or $3BeO.Al_2O_3.6SiO_2$ = Silica 67·0, alumina 19·0, glucina 14·0 = 100.

Alkalies (Na_2O, Li_2O, Cs_2O) are sometimes present replacing the beryllium, from 0·25 to 5 p. c.; also chemically combined water, including which the formula becomes $H_2Be_6Al_4Si_{12}O_{37}$.

Pyr., etc. — B.B. alone, unchanged or, if clear, becomes milky white and clouded; at a high temperature the edges are rounded, and ultimately a vesicular scoria is formed. Fusibility = 5·5, but somewhat lower for beryls rich in alkalies. Glass with borax, clear and colorless for beryl, a fine green for emerald. Unacted upon by acids.

Diff. — Characterized by its green or greenish blue color, glassy luster and hexagonal form; rarely massive, then easily mistaken for quartz. Distinguished from apatite by its hardness, not being scratched by a knife, also harder than green tourmaline; from chrysoberyl by its form; from euclase and topaz by its imperfect cleavage.

Artif. — Crystals of beryl have been produced artificially by fusing a mixture of silica, alumina and glucina with boric oxide as a flux.

Obs. — Beryl is a common accessory mineral in granite veins, especially in those of a pegmatitic character. Emeralds occur in clay slate, in isolated crystals or in nests, near Muso, etc., 75 m. N.N.E. of Bogotà, Colombia. Emeralds of less beauty, but larger, occur in Siberia, on the river Tokovoya, N. of Ekaterinburg, embedded in mica schist. Emeralds of large size, though not of uniform color or free from flaws, have been obtained in Alexander Co., N. C.

Transparent beryls are found in Siberia, India and Brazil. In Siberia they occur at Mursinka and Shaitanka, near Ekaterinburg; near Miask with topaz; in the mountains of Adun-Chalon with topaz, in E. Siberia. A clear aquamarine crystal weighing 110·5 kg. was found at Marambaya, Minas Geraes, Brazil. Beautiful crystals also occur at Elba; the tin mines of Ehrenfriedersdorf in Saxony, and Schlackenwald in Bohemia. Other localities are the Mourne Mts., Ireland; yellowish green at Rubislaw, near Aberdeen, Scotland (*davidsonite*); Limoges in France; Finbo and Broddbo in Sweden; Tamela in Finland; Pfitsch-Joch, Tyrol; Bodenmais and Rabenstein in Bavaria; in New South Wales. Pink, alkali-rich beryls are found in Madagascar.

In the United States, beryls of gigantic dimensions have been found in N. H., at Acworth and Grafton, and in Mass., at Royalston. In Me., at Albany; Norway; Bethel; at Hebron, a cæsium beryl (Cs_2O, 3·60 p. c.), associated with pollucite; in Paris, with black tourmaline; at Topsham, pale green or yellowish; at Stowe and Stoneham. In Mass., at Barre; at Goshen (*goshenite*), and at Chesterfield. In Conn., at Haddam, and at the Middletown and Portland feldspar quarries; at New Milford, of a clear golden yellow to dark amber color; Branchville. In Pa., at Leiperville and Chester; at Mineral Hill. In Va., at Amelia Court House, sometimes white. In N. C., in Alexander Co., near Stony Point, fine emeralds; in Mitchell Co.; Morganton, Burke Co., and elsewhere. In Ala., Coosa Co., of a light yellow color. In Col., near the summit of Mt. Antero, beautiful aquamarines. In S. D., in the Black Hills in large crystals. Rose-pink crystals, often showing prominent pyramid faces, from San Diego Co., Cal., also colorless and aquamarine.

Use. — The transparent mineral is used as a gem stone; see above under *Varieties*.

Eudialyte. Essentially a metasilicate of Zr,Fe(Mn),Ca,Na, etc. In red to brown tabular or rhombohedral crystals; also massive. H. = 5–5·5. G. = 2·9–3·0. Optically +. ω = 1·606. ϵ = 1·611. From Kangerdluarsuk, West Greenland, etc., with arfvedsonite and sodalite; at Lujaor on the Kola peninsula, Russian Lapland, in elæolite-syenite, there forming a main constituent of the rock-mass. *Eucolite*, from islands of the Langesund fiord in Norway, is similar (but optically –). Eudialyte and eucolite also occur at Magnet Cove, in Ark., of a rich crimson to peach-blossom red color, in feldspar, with elæolite and ægirite.

Elpidite. $Na_2O.ZrO_2.6SiO_2.3H_2O$. — Massive, fibrous. H. = 7. G. = 2·54. Color white to brick-red. Biaxial, +. Indices = 1·560–1·574. Southern Greenland.

ASTROLITE. $(Na,K)_2Fe(Al,Fe)_2(SiO_3)_5.H_2O$?. In globular forms with radiating structure. H. = 3·5. G. = 2·8. Color green. Fusible, 3·5. Found in a diabase tuff near Neumark, Germany.

The following are rare species of complex composition, all from the Langesund fiord region of southern Norway.

Catapleiite. $H_4(Na_2,Ca)ZrSi_3O_{11}$. In thin tabular hexagonal prisms. H. = 6. G. = 2·8. Color light yellow to yellowish brown. Biaxial, +. Indices, 1·591–1·627. *Natron-catapleiite*, or soda-catapleiite, contains only sodium; color blue to gray and white; on heating the blue color disappears.

Cappelenite. A boro-silicate of yttrium and barium. In greenish brown hexagonal crystals.

Melanocerite. A fluo-silicate of the cerium and yttrium metals and calcium chiefly (also B, Ta, etc.). In brown to black tabular rhombohedral crystals.

Caryocerite. Near melanocerite, containing ThO_2.

Steenstrupine (from Greenland) is allied to the two last-named species. Rhombohedral. H. = 4. G. = 3·4. Color dark brown to nearly black. Optically –.

Tritomite. A fluo-silicate of thorium, the cerium and yttrium metals and calcium, with boron. In dark brown crystals of acute triangular pyramidal form.

The following are also from the same region:

Leucophanite. $Na(BeF)Ca(SiO_3)_2$. In glassy greenish tabular crystals (orthorhombic-sphenoidal). H. = 4. G. = 2·96. Optically –. Indices, 1·571–1·598.

Meliphanite. A fluo-silicate of beryllium, calcium, and sodium near leucophanite. In low square pyramids (tetragonal). Color yellow. H. = 5–5·5. G. = 3·01. Optically –. Indices, 1·593–1·612.

Custerite. $Ca_3(OH,F)SiO_3$. Monoclinic. In fine granular masses. Cleavages parallel to base and prism, all making nearly 90° with each other. Twinning plane *c* (001), showing in twin lamellæ. H. = 5. G. = 2·91. Color greenish gray. Transparent. Optically +. Bx_a nearly perpendicular to *c* (001). Indices, 1·58–1·60. Difficultly fusible. Decomposed by hydrochloric acid. Found in limestone contact zone at the Empire mine, Custer Co., Idaho.

Didymolite. $2CaO.3Al_2O_3.9SiO_2$. Monoclinic. In small twinned crystals. H. = 4–5. G. = 2·71. Color dark gray. Opaque. Index 1·5. Difficultly fusible. Insoluble. Found as contact mineral in limestone from Tatarka River, Yenisei District, Siberia.

IOLITE. Cordierite. Dichroite.

Orthorhombic. Axes $a : b : c = 0{\cdot}5871 : 1 : 0{\cdot}5585$.

Twins: tw. pl. *m* (110), also *d* (130), both yielding pseudo-hexagonal forms. Habit short prismatic ($mm''' = 60° 50'$) (Fig. 838). As embedded grains; also massive, compact.

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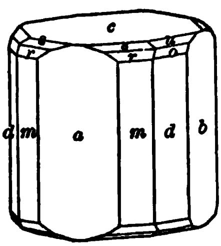
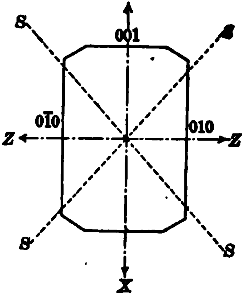


839



Cleavage: *b* (010) distinct; *a*(100) and *c*(001) indistinct. Crystals often show a lamellar structure ∥ *c* (001), especially when slightly altered. Fracture subconchoidal. Brittle. H. = 7–7·5. G. = 2·60–2·66. Luster vitreous. Color various shades of blue, light or dark, smoky blue. Transparent to translucent. Pleochroism strongly marked except in thin sections. Axial colors variable. Thus:

Bodenmais *Z* (= *b* axis) dark Berlin-blue. *Y* (= *a* axis) light Berlin-blue. *X* (= *c* axis) yellowish white.

Absorption $Z > Y > X$. Pleochroic halos common, often bright yellow; best seen in sections ∥ *c* axis. Exhibits idiophanous figures. Optically −. Ax. pl. ∥ *a* (100). Bx. ⊥ *c* (001). Dispersion feeble, $\rho < v$. 2V = 70° 23′ (also 40° to 84°). Indices variable, from 1·534 to 1·599.

Comp. — $H_2(Mg,Fe)_4Al_8Si_{10}O_{37}$ or $H_2O.4(Mg,Fe)O.4Al_2O_3.10SiO_2$.

If Mg : Fe = 7 : 2, the percentage composition is: Silica 49·4, alumina 33·6, iron protoxide 5·3, magnesia 10·2, water 1·5 = 100. Ferrous iron replaces part of the magnesium. Calcium is also present in small amount.

Pyr., etc. — B.B. loses transparency and fuses at 5–5·5. Only partially decomposed by acids. Decomposed on fusion with alkaline carbonates.

Diff. — Characterized by its vitreous luster, color and pleochroism; fusible on the edges unlike quartz; less hard than sapphire.

Micro. — Recognized in thin sections by lack of color; low refraction and low interference-colors; it is very similar to quartz, but distinguished by its biaxial character; in volcanic rocks commonly shows distinct crystal outlines and a twinning of three individuals like aragonite. In the gneisses, etc., it is in formless grains, but the common occurrence of inclusions, especially of sillimanite needles, the pleochroic halos of a yellow color around small inclusions, particularly zircons, and the constant tendency to alteration to micaceous pinite seen along cleavages, help to distinguish it.

Obs. — Occurs in granite, gneiss (*cordierite-gneiss*), hornblendic, chloritic and talcose schist, and allied rocks, with quartz, orthoclase or albite, tourmaline, hornblende, andalusite, sillimanite, garnet, and sometimes beryl. Less commonly in or connected with igneous rocks, thus formed directly from the magma, as in andesite, etc.; also in ejected masses (in fragments of older rocks); further formed as a contact-mineral in connection with eruptive dikes, as in slates adjoining granite.

Occurs at Bodenmais, Bavaria, in granite, with pyrrhotite, etc.; Orijärvi, in Finland (*steinheilite*); Tunaberg, in Sweden; from Switzerland; in colorless crystals from Brazil; Ceylon affords a transparent variety, the *saphir d'eau* of jewelers; from Ibity, Madagascar; from Greenland.

In the United States, at Haddam, Conn., associated with tourmaline in a granitic vein in gneiss. In large altered crystals from Litchfield, Conn. At Brimfield, Mass.; at Richmond, N. H.

Named *Iolite* from *'ἴον, violet,* and *λίθος, stone; Dichroite* (from *δίχροος, two-colored*), from its dichroism; *Cordierite*, after Cordier, the French geologist (1777–1861).

Alteration. The alteration of iolite takes place so readily by ordinary exposure, that the mineral is most commonly found in an altered state, or enclosed in the altered iolite. This change may be a simple hydration; or a removal of part of the protoxide bases by carbon dioxide; or the introduction of oxide of iron; or of alkalies, forming pinite and mica. The first step in the change consists in a division of the prisms of iolite into plates parallel to the base, and a pearly foliation of the surfaces of these plates; with a change of color to grayish green and greenish gray, and sometimes brownish gray. As the alteration proceeds, the foliation becomes more complete; afterward it may be lost. The mineral in this altered condition has many names: as *hydrous iolite* (including *bonsdorffite* and *auralite*) from Åbo, Finland; *fahlunite* from Falun, Sweden, also *pyrargillite* from Helsingfors; *esmarkite* and *praseolite* from near Brevik, Norway, also *raumite* from Raumo, Finland, and *peplolite* from Ramsberg, Sweden; *chlorophyllite* from Unity, Me.; *aspasiolite* and *polychroilite* from Kragerö. There are further alkaline kinds, as *pinite, cataspilite, gigantolite, iberite,* belonging to the Mica Group.

Use. — Iolite is sometimes used as a gem.

Jurupaite. $H_2(Ca,Mg)_2Si_2O_7$. Monoclinic? Radiating fibrous. White. H. = 4. G. = 2·75. n = 1·57. Crestmore, Cal.

The following are rare lead, zinc, and barium silicates:

Barysilite. $Pb_3Si_2O_7$. Rhombohedral. In embedded masses with curved lamellar structure. Cleavage: basal. H. = 3. G. = 6·11–6·55. Color white; tarnishing on exposure. From the Harstig mine, Pajsberg, and Långban, Sweden.

Molybdophyllite. $(Pb,Mg)SiO_4.H_2O$. Hexagonal. In irregular foliated masses with perfect basal cleavage. H. = 3–4. G. = 4·7. Colorless to pale green. ω = 1·81. Difficultly fusible. From Långban, Sweden.

Ganomalite. $Pb_4(PbOH)_2Ca_4(Si_2O_7)_3$. In prismatic crystals (tetragonal); also massive, granular. H. = 3. G. = 5·74. Colorless to gray. Indices, 1·83–1·93. From Långban, Sweden; also Jakobsberg.

Nasonite. Closely related to *ganomalite*. $Pb_4(PbCl)_2Ca_4(Si_2O_7)_3$. Probably tetragonal. Massive, granular cleavable. H. = 4. G. = 5·4. White. Fusible. From Franklin, N. J.

Margarosanite. $Pb(Ca,Mn)_2(SiO_3)_3$. Triclinic. Slender prismatic crystals and cleavable granular. Three cleavages, one perfect. Colorless and transparent with pearly luster. H. = 2·5–3. G. = 3·99. Easily fusible. From Franklin, N. J., and Långban, Sweden.

Hardystonite. $Ca_2ZnSi_2O_7$. Tetragonal. In granular masses. Three cleavages. H. = 3–4. G. = 3·4. Color white. From Franklin, N. J.

Hyalotekite. Approximately $(Pb,Ba,Ca)B_2(SiO_3)_{12}$. Massive; coarsely crystalline. H. = 5–5·5. G. = 3·81. Color white to pearly gray. From Långban, Sweden.

Barylite. $Ba_4Al_4Si_7O_{24}$. In groups of colorless prismatic orthorhombic crystals. H. = 7. G. = 4·03. Luster greasy. Optically +. β = 1·685. Occurs with hedyphane in crystalline limestone at Långban, Sweden.

Taramellite. $Ba_4\overset{II}{Fe}\overset{III}{Fe}_4Si_{10}O_{31}$. Orthorhombic? Fibrous. Color reddish brown. H. = 5·5. G. = 3·9. Strong pleochroism, almost black to flesh-red. Found in limestone at Candoglia, Italy.

Roeblingite. $5(H_2CaSiO_4).2(CaPbSO_4)$. In dense, white, compact, crystalline masses. H. = 3. G. = 3·433. From Franklin Furnace, N. J.

III. Orthosilicates. R_2SiO_4

Salts of Orthosilicic Acid, H_4SiO_4; characterized by an oxygen ratio of 1 : 1 for silicon to bases.

The following list includes the more prominent groups among the Orthosilicates.

A number of basic orthosilicates are here included, which yield water upon ignition; also others which are more or less basic than a normal orthosilicate, but which are of necessity introduced here in the classification, because of their relationship to other normal salts. The MICA GROUP is so closely related to many Hydrous Silicates that (with also Talc, Kaolinite, and some others) it is described later with them.

Nephelite Group. Hexagonal.
Sodalite Group. Isometric.
Helvite Group. Isometric-tetrahedral.
Garnet Group. Isometric.
Chrysolite Group. Orthorhombic.
Phenacite Group. Tri-rhombohedral.
Scapolite Group. Tetragonal-pyramidal.
Zircon Group. Tetragonal.
Danburite Group. Orthorhombic.
Datolite Group. Monoclinic.
Epidote Group. Monoclinic.

Nephelite Group. Hexagonal

Typical formula $\overset{\text{I}}{R}AlSiO_4$

Nephelite	$K_2Na_6Al_8Si_9O_{34}$		$c = 0{\cdot}8389$
Soda-nephelite (artif.)	$NaAlSiO_4$		
Eucryptite	$LiAlSiO_4$	**Kaliophilite**	$KAlSiO_4$

Cancrinite	$H_6Na_6Ca(NaCO_3)_2Al_8(SiO_4)_9$	$2c = 0{\cdot}8448$
Microsommite	$(Na,K)_{10}Ca_4Al_{12}Si_{12}O_{52}SCl_4$	$2c = 0{\cdot}8367$

The species of the NEPHELITE GROUP are hexagonal in crystallization and have in part the typical orthosilicate formula $\overset{\text{I}}{R}AlSiO_4$. From this formula nephelite itself deviates somewhat, though an artificial soda-nephelite, $NaAlSiO_4$, conforms to it. The species Cancrinite and Microsommite are related in form and also in composition, though in the latter respect somewhat complex. They serve to connect this group with the sodalite group following.

NEPHELITE. Nepheline. Elæolite.

Hexagonal-hemimorphic (p. 101). Axis $c = 0{\cdot}83893$.

In thick six- or twelve-sided prisms with plane or modified summits. Also massive compact, and in embedded grains; structure sometimes thin columnar.

Cleavage: *m* (110) distinct; *c* (001) imperfect. Fracture subconchoidal. Brittle. H. = 5·5–6. G. = 2·55–2·65. Luster vitreous to greasy; a little opalescent in some varieties. Colorless, white, or yellowish; also, when massive, dark green, greenish or bluish gray, brownish red and brick-red. Transparent to opaque. Optically −. Indices: $\omega = 1{\cdot}542$, $\epsilon = 1{\cdot}538$.

Var. — 1. *Nephelite. Glassy.* — Usually in small glassy crystals or grains, transparent with vitreous luster, first found on Mte. Somma, Vesuvius. Characteristic particularly of younger eruptive rocks and lavas. 2. *Elæolite.* — In large coarse crystals, or more commonly massive, with a greasy luster, and reddish, greenish, brownish or gray in color. Usually clouded by minute inclusions. Characteristic of granular crystalline rocks, syenite, etc.

Comp. — $NaAlSiO_4$. This is the composition of the artificial mineral. Natural nephelite always contains silica in varying excess and also small amounts of potash. The composition usually approximates to $Na_6K_2Al_8Si_9O_{34}$.

Synthetic experiments, yielding crystals like nephelite with the composition $NaAlSiO_4$, lead to the conclusion that a natural soda-nephelite would be an orthosilicate with this formula, while the higher silica in the potash varieties may be explained by the presence, in molecular combination, of $KAlSiO_4$ and $NaAlSi_3O_8$ (albite in hexagonal modification). The variation in composition may be more simply explained by considering normal nephelite, $NaAlSiO_4$, to take up in solid solution silica or other silicate molecules. The other species of the group are normal orthosilicates, viz., eucryptite $LiAlSiO_4$, and kaliophilite, $KAlSiO_4$.

Pyr., etc. — B.B. fuses quietly at 3·5 to a colorless glass, coloring the flame yellow. Gelatinizes with acids.

Diff. — Distinguished by its gelatinizing with acids from scapolite and feldspar, as also from apatite, from which it differs too in its greater hardness. Massive varieties have a characteristic greasy luster.

Micro. — Recognized in thin sections by its low refraction; very low interference-colors, which scarcely rise to gray; parallel extinction when in crystals; faint negative uniaxial cross yielded by basal sections in converging light. The negative character is best told by aid of the gypsum plate (see p. 266). Micro-chemical tests serve to distinguish non-characteristic particles from similar ones of alkali feldspar; the section is treated with dilute acid, and the resultant gelatinous silica, which coats the nephelite particles, stained with eosine or other dye.

Artif. — Nephelite is easily prepared artificially by fusing its constituents together in the proper proportions.

Obs. — Nephelite is rather widely distributed (as shown by the microscopic study of rocks) in igneous rocks as the product of crystallization of a magma rich in soda and at the same time low in silica (which last prevents the soda from being used up in the formation of albite). It is thus an essential component of the nephelite-syenites and phonolites where it is associated with alkali feldspars chiefly. It is also a constituent of more basic augitic rocks such as nephelinite, nephelite-basalts, nephelite-tephrites, theralite, etc., most of which are volcanic in origin. The variety *elæolite* is associated with the granular plutonic rocks, while the name *nephelite* was originally used for the fresh glassy crystals of the modern lavas; the terms have in this sense the same relative significance as orthoclase and sanidine. Modern usage, however, tends to drop the name *elæolite.*

The original *nephelite* occurs in crystals in the older lavas of Mte. Somma, Vesuvius, with mica, vesuvianite, etc.; at Capo di Bove, near Rome; in the basalt of Katzenbuckel, near Heidelberg, Germany; Aussig in Bohemia; Löbau in Saxony. Occurs also in massive forms and large coarse crystals (*elæolite*) in the nephelite-syenites of Southern Norway, especially along the Langesund fiord; similarly in west Greenland; the peninsula of Kola, Russia; Miask in the Ilmen Mts. (in the rock *miascite*); Sierra Monchique, Portugal (in the rock *foyaite*); Ditró, Hungary (in the rock *ditroite*); Pousac, France; Brazil; South Africa.

Elæolite occurs massive and crystallized at Litchfield, Me., with cancrinite; Salem, Mass.; Red Hill, N. H.; in the Ozark Mts., near Magnet Cove, Ark.; elæolite-syenite is also found near Beemersville, northern N. J.; near Montreal, Canada; at Dungannon township, Ontario, in enormous crystals. Nephelite rocks also occur at various points, as the Transpecos district, Texas; Pilot Butte, Texas; also in western North America, as in Col. at Cripple Creek; in Mon., in the Crazy Mts., the Highwood, Bearpaw and Judith Mts.; Black Hills in S. D.; Ice River, British Columbia.

Named *nephelite* from *νεφέλη, a cloud,* in allusion to its becoming cloudy when immersed in strong acid; *elæolite* is from *ελαίον, oil,* in allusion to its greasy luster.

Gieseckite is a pseudomorph after nephelite. It occurs in Greenland in six-sided greenish gray prisms of greasy luster; also at Diana in Lewis Co., N. Y. *Dysyntribite* from Diana is similar to gieseckite, as is also *liebenerite,* from the valley of Fleims, in Tyrol, Austria. See further PINITE under the MICA GROUP.

Eucryptite. $LiAlSiO_4$. In symmetrically arranged crystals (hexagonal), embedded, in albite and derived from the alteration of spodumene at Branchville, Conn. (see Fig. 488, p. 181). G. = 2·667. Colorless or white.

Kaliophilite. $KAlSiO_4$. Phacellite. Phacelite. Facellite. In bundles of slender acicular crystals (hexagonal), also in fine threads, cobweb-like. H. = 6. G. = 2·493–2·602. Colorless. Occurs in ejected masses at Mte. Somma, Vesuvius.

CANCRINITE.

Hexagonal. Axis $c = 0{\cdot}4224$; and *mp* $10\bar{1}0 \wedge 10\bar{1}1 = 64°$, *pp′* $1011 \wedge 01\bar{1}1 = 25° 58'$. Rarely in prismatic crystals with a low terminal pyramid. Usually massive.

Cleavage: prismatic, *m* $(10\bar{1}0)$ perfect; *a* $(11\bar{2}0)$ less so. H. = 5–6. G. = 2·42–2·5. Color white, gray, yellow, green, blue, reddish. Streak uncolored. Luster subvitreous, or a little pearly or greasy. Transparent to translucent. Optically −. $\omega = 1{\cdot}524$. $\epsilon = 1{\cdot}496$.

Comp. — $H_6Na_6Ca(NaCO_3)_2Al_8(SiO_4)_9$ or $3H_2O.4Na_2O.CaO.4Al_2O_3.9SiO_2.2CO_2$ = Silica 38·7, carbon dioxide 6·3, alumina 29·3, lime 4·0, soda 17·8, water 3·9 = 100.

Pyr., etc. — In the closed tube gives water. B.B. loses color, and fuses (F. = 2) with intumescence to a white blebby glass, the very easy fusibility distinguishing it readily from nephelite. Effervesces with hydrochloric acid, and forms a jelly on heating, but not before.

Micro. — Recognized in thin sections by its low refraction; quite high interference-colors and negative uniaxial character. Its common association with nephelite, sodalite, etc., are valuable characteristics. Evolution of CO_2 with acid distinguishes it from all other minerals except the carbonates, which show much higher interference-colors.

Artif. — Cancrinite has been prepared artificially by heating under pressure a mixture of sodium silicate, alumina and sodium carbonate; also by the treatment of nephelite and labradorite by sodium carbonate at high temperatures.

Obs. — Cancrinite occurs only in igneous rocks of the nephelite-syenite and related rock groups. It is in part believed to be original, i.e., formed directly from the molten magma; in part held to be secondary and formed at the expense of nephelite by infiltrating waters holding calcium carbonate in solution. Prominent localities are Miask in the Ilmen Mts., Russia, in coarse-grained nephelite-syenite; similarly at Barkevik and other localities on the Langesund fiord in southern Norway; in the parish of Knolajärvi in northern Finland (where, associated with orthoclase, ægirite and nephelite, it composes a mass of cancrinite-syenite); at Ditró, Transylvania, etc.; in nephelite-syenite of Sarna and Alnö in Sweden, and in Brazil; also in small amount as an occasional accessory component of many phonolitic rocks at various localities.

In the United States at Litchfield and West Gardiner, Me., with elæolite and blue sodalite. Named after Count Cancrin, Russian Minister of Finance.

SULPHATIC CANCRINITE with nearly one-half the CO_2 replaced by SO_3 is found in an altered rock on Beaver Creek, Gunnison Co., Col. Has lower refractive indices and birefringence than *cancrinite*.

Microsommite. Near cancrinite; perhaps $(Na,K)_{10}Ca_4Al_{12}Si_{12}O_{52}SCl_4)$. In minute colorless prismatic crystals (hexagonal. See Fig. 30, p. 19). From Vesuvius (Monte Somma). H. = 6. G. = 2·42–2·53. $\omega = 1{\cdot}521$. $\epsilon = 1{\cdot}529$.

Davyne. Near microsommite. From Mte. Somma; Laacher See, Germany. $\omega = 1{\cdot}518$. $\epsilon = 1{\cdot}521$.

Sodalite Group. Isometric

Sodalite	$Na_4(AlCl)Al_2(SiO_4)_3$
Haüynite	$(Na_2,Ca)_2(NaSO_4.Al)Al_2(SiO_4)_3$
Noselite	$Na_4(NaSO_4.Al)Al_2(SiO_4)_3$
Lazurite	$Na_4(NaS_3.Al)Al_2(SiO_4)_3$

The species of the Sodalite Group are isometric in crystallization and perhaps tetrahedral like the following group. In composition they are peculiar (like cancrinite of the preceding group) in containing radicals with Cl, SO_4 and S, which are elements usually absent in the silicates. These are shown in the formulas written above in the form suggested by Brögger, who shows that this group and the one following may be included with the garnets in a broad group characterized by isometric crystallization and a close resemblance in composition. See further under the GARNET GROUP proper, p. 505.

The formulas are also often written as if the compound consisted of a silicate and chloride (sulphate, sulphide) — thus for sodalite, $3NaAlSiO_4 + NaCl$, etc.

SODALITE.

Isometric, perhaps tetrahedral. Common form the dodecahedron. Twins: tw. pl. *o* (111), forming hexagonal prisms by elongation in the direction of an octahedral axis (Fig. 406, p. 165). Also massive, in embedded grains; in concentric nodules resembling chalcedony, formed from elæolite.

Cleavage: dodecahedral, more or less distinct. Fracture conchoidal to uneven. Brittle. H. = 5·5–6. G. = 2·14–2·30. Luster vitreous, sometimes inclining to greasy. Color gray, greenish, yellowish, white; sometimes blue, lavender-blue, light red. Transparent to translucent. Streak uncolored. $n = 1·4827$.

Comp. — $Na_4(AlCl)Al_2(SiO_4)_3$ = Silica 37·2, alumina 31·6, soda 25·6, chlorine 7·3 = 101·7, deduct (O = 2Cl) 1·7 = 100. Potassium replaces a small part of the sodium. The formula may also be written $3NaAlSiO_4 + NaCl$.

Pyr., etc. — In the closed tube the blue varieties become white and opaque. B.B. fuses with intumescence, at 3·5–4, to a colorless glass. Soluble in hydrochloric acid and yields gelatinous silica upon evaporation.

Diff. — Distinguished from much analcite, leucite and haüynite by chemical tests alone; dissolving the mineral in dilute nitric acid and testing for chlorine is the simplest and best.

Micro. — Recognized in thin sections by its very low refraction, isotropic character and lack of good cleavage; also, in most cases, by its lack of color. In uncovered rock sections the minerals of this group may be distinguished from each other by covering them with a little nitric acid which is allowed to evaporate slowly. With sodalite crystals of sodium chloride will form; with haüynite crystals of gypsum; with noselite crystals of both compounds after the addition of calcium chloride; lazurite will evolve hydrogen sulphide which will blacken silver.

Artif. — Sodalite can be obtained by fusing nephelite with sodium chloride; also by the action of sodium carbonate and caustic soda upon muscovite at 500°. It has been produced also in various artificial magmas at temperatures below 700°.

Obs. — Sodalite occurs only in igneous rocks of the nephelite-syenite and related rock groups, as a product of the crystallization of a magma rich in soda; also as a product associated with enclosed masses and bombs ejected with such magmas in the form of lava, as at Vesuvius. Often associated with nephelite (or elæolite), cancrinite and eudialyte. With sanidine it forms a *sodalite-trachyte* at Scarrupata in Ischia, Italy, in crystals. In Sicily, Val di Noto, with nephelite and analcite. At Vesuvius, in bombs on Monte Somma in white, translucent, dodecahedral crystals; massive and of a gray color at the Kaiserstuhl and near Lake Laach, Germany. A variety from Monte Somma containing 2 per cent of molybdenum trioxide has been called *molybdosodalite*. At Ditró, Transylvania, in an elæolite-syenite. In the foyaite of southern Portugal. At Miask, in the Ilmen Mts., Russia; in the augite-syenite of the Langesund-fiord region in Norway. Further in West Greenland in sodalite-syenite; the peninsula of Kola, Russia.

A blue massive variety occurs at Litchfield and West Gardiner, Me. Occurs in the theralite of the Crazy Mts., Mon., also at Square Butte, Highwood Mts., and in the Bearpaw Mts., in tinguaite. Occurs also in the elæolite-syenite of Brome, Brome Co., and of Montreal and Belœil, province of Quebec; at Dungannon, Ontario, in large blue masses and in small pale pink crystals. At Kicking Horse Pass, Bristish Columbia.

Hackmanite. A sodalite containing about 6 per cent of the molecule $Na_4[Al(NaS)]Al_2(SiO_4)_3$ from a rock called *tawite* from the Tawa valley on the Kola peninsula, Lapland.

HAÜYNITE. Haüyne.

Isometric. Sometimes in dodecahedrons, octahedrons, etc.

Twins: tw. pl. *o* (111); contact-twins, also polysynthetic; penetration-twins (Fig. 405, p. 165). Commonly in rounded grains, often looking like crystals with fused surfaces.

Cleavage: dodecahedral, rather distinct. Fracture flat conchoidal to uneven. Brittle. H. = 5·5–6. G. = 2·4–2·5. Luster vitreous, to somewhat greasy. Color bright blue, sky blue, greenish blue; asparagus-green, red, yellow. Streak slightly bluish to colorless. Subtransparent to translucent; often enclosing symmetrically arranged inclusions (Fig. 840). n = 1·4961.

Comp. — $Na_2Ca(NaSO_4.Al)Al_2(SiO_4)_3$. This is analogous to the garnet formula (Brögger) where the place of the R_3 is taken by Na_2, Ca and the group Na–O–SO_2–O–Al. The percentage composition is: Silica 32·0, sulphur trioxide 14·2, alumina 27·2, lime 10·0, soda 16·6 = 100. The ratio of Na_2 : Ca also varies from 3 : 2; potassium may be present in small amount. The formula may also be written $2(Na_2,Ca)Al_2(SiO_4)_2 + (Na\ ,Ca)SO_4$.

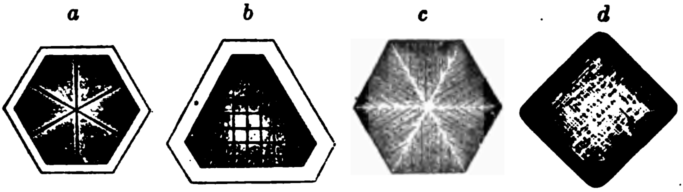
Pyr., etc. — In the closed tube retains its color. B.B. in the forceps fuses at 4·5 to a white glass. Soluble in hydrochloric acid and yields gelatinous silica upon evaporation. The solution gives a test for the sulphate radical with barium chloride.

Micro. — Similar to sodalite, which see.

Artif. — Has been produced artificially in the same ways as with sodalite with the use of a sulphate instead of a chloride.

Obs. — Common in certain igneous rocks, thus in haüynophyre, in phonolite, tephrite; very commonly associated with nephelite and leucite. Occurs in the Vesuvian lavas, on Mte. Somma; at Melfi, on Mt. Vultur, Naples; in the lavas of the Campagna, Rome, also in a basalt tuff near Albano, Italy; at Niedermendig, in the Eifel, Germany; the phonolites of Hohentwiel, Baden, Germany.

840



Section of crystals of haüynite (after Möhl)

Noselite or Nosean. Near haüynite, but contains little or no lime. Color grayish, bluish, brownish; sometimes nearly opaque from the presence of inclusions (cf. Fig. 840). n = 1·495. Not uncommon in phonolite. In Germany at Andernach, the Laacher See, and elsewhere.

LAZURITE. LAPIS-LAZULI. Lasurite.

Isometric. In cubes and dodecahedrons. Commonly massive, compact.

Cleavage: dodecahedral, imperfect. Fracture uneven. H. = 5–5·5. G. = 2·38–2·45. Luster vitreous. Color rich Berlin-blue or azure-blue, violet-blue, greenish blue. Translucent. n = 1·500.

Comp. — Essentially $Na_4(NaS\ .Al)Al_2(SiO_4)_3$, but containing also in molecular combination haüynite and sodalite. The percentage composition of this ultramarine compound is as follows: Silica 31·7, alumina 26·9, soda 27·3, sulphur 16·9 = 102·9, or deduct (O = S) 2·9 = 100.

The heterogeneous character of what had long passed as a simple mineral under the name Lapis-lazuli was shown by Fischer (1869), Zirkel (1873), and more fully by Vogelsang (1873).

The ordinary natural *lapis lazuli* is shown by Brögger and Bäckström to contain lazurite or haüynite (sometimes changed to a zeolite), a diopside free from iron, amphibole (koksharovite), mica (muscovite), calcite, pyrite; also in some varieties in relatively small amount scapolite, plagioclase, orthoclase (microperthite?), apatite, titanite, zircon, and an undetermined mineral optically + and probably uniaxial. Regarded by Brögger as a result of contact metamorphism in limestone.

Micro. — Similar to sodalite, which see.

Pyr., etc. — Heated in the closed tube gives off some moisture; the variety from Chile glows with a beetle-green light, but the color of the mineral remains blue on cooling. Fuses easily (3) with intumescence to a white glass. Soluble in hydrochloric acid and yields gelatinous silica upon evaporation and evolves hydrogen sulphide.

Obs. — Occurs in Badakshan, India, in the valley of the Kokcha, a branch of the Oxus, a few miles above Firgamu. Also at the south end of Lake Baikal, Siberia. Further, in Chile in the Andes of Ovalle. In ejected masses at Monte Somma, Vesuvius, rare. From Siberia and Persia.

Use. — The richly colored varieties of lapis lazuli are highly esteemed for costly vases and ornamental furniture; also employed in the manufacture of mosaics; and when powdered constitutes the rich and durable paint called *ultramarine*. This has been replaced, however, by artificial ultramarine, now an important commercial product.

𝔠. *Helvite Group.* Isometric-tetrahedral

Helvite	$(Mn,Fe)_2(Mn_2S)Be_3(SiO_4)_3$
Danalite	$(Fe,Zn,Mn)_2((Zn,Fe)_2S)Be_3(SiO_4)_3$
Eulytite	$Bi_4(SiO_4)_3$
Zunyite	$(Al(OH,F,Cl)_2)_6Al_2(SiO_4)_3$

The HELVITE GROUP includes several rare species, isometric-tetrahedral in crystallization and in composition related to the species of the SODALITE GROUP and also to those of the GARNET GROUP which follows:

HELVITE.

Isometric-tetrahedral. Commonly in tetrahedral crystals; also in spherical masses.

Cleavage: octahedral in traces. Fracture uneven to conchoidal. Brittle. H. = 6–6·5. G. = 3·16–3·36. Luster vitreous, inclining to resinous. Color honey-yellow, inclining to yellowish brown, and siskin-green, reddish brown. Streak uncolored. Subtransparent. $n = 1{\cdot}739$. Pyroelectric.

Comp. — $(Be,Mn,Fe)_7Si_3O_{12}S$. This may be written $(Mn,Fe)_2(Mn_2S)Be_3(SiO_4)_3$ analogous to the Garnet Group, the bivalent group –Mn–S–Mn taking the place of a bivalent element, R, and 3Be corresponding to 2Al, cf. p. 505. Composition also written $3(Be,Mn,Fe)_2SiO_4.(Mn,Fe)S$.

Pyr., etc. — Fuses at 3 in R.F. with intumescence to a yellowish brown opaque bead, becoming darker in R.F. With the fluxes gives the manganese reaction. Soluble in hydrochloric acid, giving hydrogen sulphide and yielding gelatinous silica upon evaporation.

Obs. — Occurs at Schwarzenberg and Breitenbrunn, in Saxony; at Kapnik, Hungary; also in the pegmatite veins of the augite-syenite of the Langesund fiord, Norway; in the Ilmen Mts., Russia, near Miask, in pegmatite. In the United States, with spessartite, at the mica mines near Amelia Court-House, Amelia Co., Va.; etc. Named by Werner, in allusion to its yellow color, from ἥλιος, *the sun*.

Danalite. $(Be,Fe,Zn,Mn)_7Si_3O_{12}S$. In octahedrons; usually massive. H. = 5·5–6. G. = 3·427. Color flesh-red to gray. Occurs in small grains in the Rockport granite, Cape Ann, Mass.; at the iron mine at Bartlett, N. H.; El Paso Co., Col. In England at Redruth, Cornwall.

Eulytite. $Bi_4Si_3O_{12}$. Usually in minute tetrahedral crystals; also in spherical forms. H. = 4·5. G. = 6·106. Color dark hair-brown to grayish, straw-yellow, or colorless. $n = 2{\cdot}05$. Found with native bismuth near Schneeberg, Saxony; also at Johanngeorgenstadt, Germany, in crystals on quartz.

Zunyite. — A highly basic orthosilicate of aluminium, $(Al(OH,F,Cl)_2)_6Al_2Si_3O_{12}$. In minute transparent tetrahedrons. H. = 7. G. = 2·875. From the Zuñi mine, near Silverton, San Juan Co., and on Red Mountain, Ouray Co., Col.

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4. *Garnet Group.* Isometric

$$\overset{II}{R}_3\overset{III}{R}_2(SiO_4)_3 \quad \text{or} \quad 3RO.R_2O_3.3SiO_2.$$

$$\overset{II}{R} = Ca,Mg,\overset{II}{Fe},\overset{II}{Mn}. \qquad \overset{III}{R} = Al,\overset{III}{Fe},\overset{III}{Cr},Ti.$$

Garnet

A. GROSSULARITE	$Ca_3Al_2(SiO_4)_3$	E. ANDRADITE	$Ca_3Fe_2(SiO_4)_3$
B. PYROPE	$Mg_3Al_2(SiO_4)_3$	Also	$(Ca,Mg)_3Fe_2(SiO_4)_3$,
C. ALMANDITE	$Fe_3Al_2(SiO_4)_3$		$Ca_3Fe_2((Si,Ti)O_4)_3$
D. SPESSARTITE	$Mn_3Al_2(SiO_4)_3$	F. UVAROVITE	$Ca_3Cr_2(SiO_4)_3$,
Schorlomite	$Ca_3(Fe,Ti)_2((Si,Ti)O_4)_3$		

The GARNET GROUP includes a series of important sub-species included under the same specific name. They all crystallize in the normal class of the isometric system and are alike in habit, the dodecahedron and trapezohedron being the common forms. They have also the same general formula, and while the elements present differ widely, there are many intermediate varieties. Some of the garnets include titanium, replacing silicon, and thus they are connected with the rare species schorlomite, which probably also has the same general formula.

Closely related to the GARNET GROUP proper are the species of the Sodalite and Helvite Groups (pp. 501, 504). All are characterized by isometric crystallization, and all are orthosilicates, with similar chemical structure. Thus the formula of the Garnet Group is $\overset{II}{R}_3\overset{III}{R}_2(SiO_4)_3$; to this Sodalite conforms if written $Na_4(AlCl)Al_2(SiO_4)_3$, where Na_4 and the bivalent radical AlCl are equivalent to R_3; similarly for Noselite (Haüynite) if the presence of the bivalent group $NaSO_4$–Al is assumed.

In the Helvite Group, which is characterized by the tetrahedral character of the species (perhaps true also of the Sodalites), the chemical relation is less close but probably exists, as exhibited by writing the formula of Helvite $(Mn,Fe)(Mn_2S)Be_3(SiO_4)_3$, where the bivalent group –S–Mn–S– enters, and 3Be may be regarded as taking the place of 2Al.

GARNET.

Isometric. The dodecahedron and trapezohedron, *n* (211), the common

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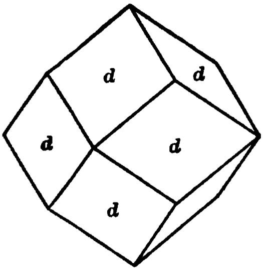

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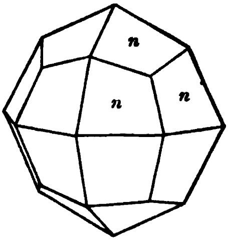

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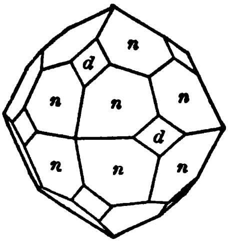

simple forms; also these in combination, or with the hexoctahedron *s* (321). Cubic and octahedral faces rare. Often in irregular embedded grains. Also massive; granular, coarse or fine, and sometimes friable; lamellar, lamellæ thick and bent. Sometimes compact, cryptocrystalline like nephrite.

Parting: *d* (110) sometimes rather distinct. Fracture subconchoidal to uneven. Brittle, sometimes friable when granular massive; very tough when compact cryptocrystalline. H. = 6·5–7·5. G. = 3·15–4·3, varying with the composition. Luster vitreous to resinous. Color red, brown, yellow, white, apple-green, black; some red and green, colors often bright. Streak white. Transparent to subtranslucent. Often exhibits anomalous double refraction, especially grossularite (also topazolite, etc.), see Art. 429. Refractive index rather high, and varying directly with the composition. The different pure molecules have approximately the following indices.

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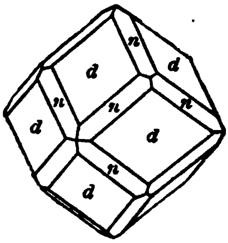

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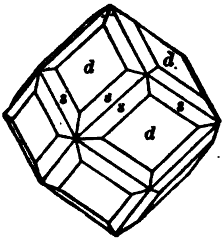

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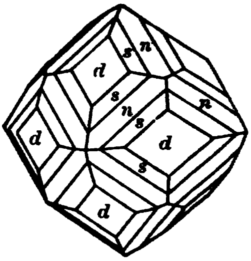

Pyrope 1·705, Grossularite 1·735, Spessartite 1·800, Almandite 1·830, Uvarovite 1·870, Andradite 1·895.

Comp. — An orthosilicate having the general formula $\overset{II}{R}_3\overset{III}{R}_2(SiO_4)_3$, or $3RO.R_2O_3.3SiO_2$. The bivalent element may be calcium, magnesium, ferrous iron or manganese; the trivalent element, aluminium, ferric iron or chromium, rarely titanium; further, silicon is also sometimes replaced by titanium. The different garnet molecules are isomorphous with each other although there are apparently definite limits to their miscibility. The greater majority will be found to have two or three component molecules; in the case, however, where three are present one is commonly in subordinate amount. The index of refraction and specific gravity vary directly with the variation in composition.

Var. — There are three prominent groups, and various subdivisions under each, many of these blending into each other.

I. *Aluminium Garnet*, including

A. GROSSULARITE	Calcium-Aluminium Garnet	$Ca_3Al_2(SiO_4)_3$
B. PYROPE	Magnesium-Aluminium Garnet	$Mg_3Al_2(SiO_4)_3$
C. ALMANDITE	Iron-Aluminium Garnet	$Fe_3Al_2(SiO_4)_3$
D. SPESSARTITE	Manganese-Aluminium Garnet	$Mn_3Al_2(SiO_4)_3$

II. *Iron Garnet*, including

E. ANDRADITE	Calcium-Iron Garnet	$Ca_3Fe_2(SiO_4)_3$

(1) Ordinary. (2) Magnesian. (3) Titaniferous. (4) Yttriferous.

III. *Chromium Garnet.*

F. UVAROVITE	Calcium-Chromium Garnet	$Ca_3Cr_2(SiO_4)_3$

The name Garnet is from the Latin *granatus*, meaning *like a grain*, and directly from *pomegranate*, the seeds of which are small, numerous, and red, in allusion to the aspect of the crystals.

A. Grossularite. Essonite or Hessonite. Cinnamon-stone. *Calcium-aluminium Garnet.* Formula $3CaO.Al_2O_3.3SiO_2$ = Silica 40·0, alumina 22·7, lime 37·3 = 100. Often containing ferrous iron replacing the calcium, and ferric iron replacing aluminium, and hence graduating toward groups C and E. G. = 3·53. Color (*a*) colorless to white; (*b*) pale green; (*c*) amber- and honey-yellow; (*d*) wine-yellow, brownish yellow, cinnamon-brown; (*e*) rose-red; rarely (*f*) emerald-green from the presence of chromium. Often shows optical anomalies (Art. 429).

The original *grossularite* (*wiluite* in part) included the pale green from Siberia, and was so named from the botanical name for the gooseberry; G. = 3·42–3·72. *Cinnamon-stone*, or *essonite* (more properly *hessonite*), included a cinnamon-colored variety from Ceylon, there called *hyacinth;* but under this name the yellow and yellowish red kinds are usually included; named from *ἥσσων*, *inferior*, because of less hardness than the true hyacinth which it resembles. *Succinite* is an amber-colored kind from the Ala valley, Piedmont, Italy. *Romanzovite* is brown.

Pale green, yellowish, and yellow-brown garnets are not invariably grossularite; some (including topazolite, demantoid, etc.) belong to the group of Calcium-Iron Garnet, or Andradite.

B. Pyrope. Precious garnet in part. *Magnesium-aluminium Garnet.* Formula $3MgO.Al_2O_3.3SiO_2$ = Silica 44·8, alumina 25·4, magnesia 29·8 = 100. Magnesia predominates, but calcium and iron are also present; the original pyrope also contained chromium. G. = 3·51. Color deep red to nearly black. Often perfectly transparent and then prized as a gem. The name *pyrope* is from *πυρωπός*, *fire-like.*

Rhodolite, of delicate shades of pale rose-red and purple, brilliant by reflected light, corresponds in composition to two parts of pyrope and one of almandite; from Macon Co., N. C.

C. Almandite. Almandine. Precious garnet in part. Common garnet in part. *Iron-aluminium Garnet.* Formula $3FeO.Al_2O_3.3SiO_2$ = Silica 36·2, alumina 20·5, iron protoxide 43·3 = 100. Ferric iron replaces the aluminium to a greater or less extent. Magnesium also replaces the ferrous iron, and thus it graduates toward pyrope, cf. rhodolite above. G. = 4·25. Color fine deep red, transparent, in *precious garnet;* brownish red, translucent or subtranslucent, in *common garnet;* black. Part of common garnet belongs to *Andradite.*

The Alabandic carbuncles of Pliny were so called because cut and polished at Alabanda. Hence the name almandine or almandite, now in use.

D. Spessartite. Spessartine. *Manganese-aluminium Garnet.* Formula $3MnO.Al_2O_3.3SiO_2$ = Silica 36·4, alumina 20·6, manganese protoxide 43·0 = 100. Ferrous iron replaces the manganese to a greater or less extent, and ferric iron also the aluminium. G. = 4·18. Color dark hyacinth-red, sometimes with a tinge of violet, to brownish red.

E. Andradite. Common Garnet, Black Garnet, etc. *Calcium-iron Garnet.* Formula $3CaO.Fe_2O_3.3SiO_2$ = Silica 35·5, iron sesquioxide 31·5, lime 33·0 = 100. Aluminium replaces the ferric iron; ferrous iron, manganese and sometimes magnesium replace the calcium. G. = 3·75. Colors various: wine-, topaz- and greenish yellow, apple-green to emerald-green; brownish red, brownish yellow; grayish green, dark green; brown; grayish black, black.

Named *Andradite* after the Portuguese mineralogist, d'Andrada, who in 1800 described and named one of the included subvarieties, Allochroite. Chemically there are the following varieties:

1. Simple *Calcium-iron Garnet*, in which the protoxides are wholly or almost wholly lime. Includes: (*a*) *Topazolite*, having the color and transparency of topaz, and also sometimes green; crystals often showing a vicinal hexoctahedron. *Demantoid*, a grass-green to emerald-green variety with brilliant diamond-like luster, used as a gem. (*b*) *Colophonite*, a coarse granular kind, brownish yellow to dark reddish brown in color, resinous in luster, and usually with iridescent hues; named after the resin *colophony*. (*c*) *Melanite* (from *μέλας, black*), black, either dull or lustrous; but all black garnet is not here included. *Pyreneite* is grayish black melanite. (*d*) Dark green garnet, not distinguishable from some allochroite, except by chemical trials.

2. *Manganesian Calcium-iron Garnet.* (*a*) *Rothoffite.* The original *allochroite* was a manganesian iron-garnet of brown or reddish brown color, and of fine-grained massive structure. *Rothoffite*, from Långban, Sweden, is similar, yellowish brown to liver-brown. Other common kinds of manganesian iron-garnet are light and dark, dusky green and black, and often in crystals. *Polyadelphite* is a massive brownish yellow kind, from Franklin Furnace, N. J. *Bredbergite*, from Sala, Sweden, contains a large amount of magnesia. (*b*) *Aplome* (properly haplome) has its dodecahedral faces striated parallel to the shorter diagonal, whence Haüy inferred that the fundamental form was the cube; and as this form is simpler than the dodecahedron, he gave it a name derived from ἁπλόος, simple. Color of the original aplome (of unknown locality) dark brown; also found yellowish green and brownish green at Schwarzenberg in Saxony, and on the Lena in Siberia.

3. *Titaniferous.* Contains titanium and probably both TiO_2 and Ti_2O_3; formula hence $3CaO.(Fe,Ti,Al)_2O_3.3(Si,Ti)O_2$. It thus graduates toward schorlomite. Color black.

4. *Yttriferous Calcium-iron Garnet.* Contains yttria in small amount; rare.

F. UVAROVITE. Ouvarovite. Uwarowit. *Calcium-chromium Garnet.* Formula $3CaO.Cr_2O_3.3SiO_2$ = Silica 35·9, chromium sesquioxide 30·6, lime 33·5 = 100. Aluminium takes the place of the chromium in part. H. = 7·5. G. = 3·41–3·52. Color emerald-green.

Pyr. etc. — Most varieties of garnet fuse easily to a light brown or black glass; F. = 3 in almandite, spessartite, and grossularite; 3·5 in andradite and pyrope; but uvarovite, the chrome-garnet, is almost infusible, F. = 6. Andradite and almandite fuse to a magnetic globule. Reactions with the fluxes vary with the bases. Almost all kinds react for iron; strong manganese reaction in spessartite, and less marked in other varieties; a chromium reaction in uvarovite, and in most pyrope. Some varieties are partially decomposed by acids; all except uvarovite after ignition become soluble in hydrochloric acid, and generally yield gelatinous silica on evaporation. Decomposed on fusion with alkaline carbonates.

The density of garnets is largely diminished by fusion. Thus a Greenland garnet fell from 3·90 to 3·05 on fusion, and a Vilui grossularite from 3·63 to 2·95.

Diff. — Characterized by isometric crystallization, usually in isolated crystals, dodecahedrons or trapezohedrons; massive forms rare, then usually granular. Also distinguished by hardness, vitreous luster, and in the common kinds the fusibility. Vesuvianite fuses more easily, zircon and quartz are infusible; the specific gravity is higher than for tourmaline, from which it differs in form; it is much harder than sphalerite.

Micro. — Distinguished in thin sections by its very high relief; lack of cleavage; isotropic character; usually shows a pale pink color; sometimes not readily told from some of the spinels.

Artif. — While members of the garnet group have been formed artificially their synthesis is difficult. Apparently they can be produced only under exact conditions of temperature and pressure that are difficult to reproduce. Natural garnets when fused break down into various other minerals.

Obs. — *Grossularite* is especially characteristic of metamorphosed impure calcareous rocks, whether altered by local igneous or general metamorphic processes; it is thus commonly found in the contact zone of intruded igneous rocks and in the crystalline schists. *Almandite* is characteristic of the mica schists and metamorphic rocks containing alumina and iron; it occurs also in some igneous rocks as the result of later dynamic and metamorphic processes; it forms with the variety of amphibole called smaragdite the rock eclogite. *Pyrope* is especially characteristic of such basic igneous rocks as are formed from magmas containing much magnesia and iron with little or no alkalies, as the peridotites, dunites, etc.; also found in the serpentines formed from these rocks; then often associated with spinel, chromite, etc. *Spessartite* occurs in granitic rocks, in quartzite, in whetstone schists (Belgium); it has been noted with topaz in lithophyses in rhyolite (Colorado). The black variety of andradite, *melanite*, is common in eruptive rocks, especially with nephelite, leucite, thus in phonolites, leucitophyres, nephelinites: in such cases often titaniferous or associated with a titaniferous garnet, sometimes in zonal intergrowth; it also occurs as a product of contact metamorphism. *Demantoid* occurs in serpentine. *Uvarovite* belongs particularly with chromite in serpentine; it occurs also in granular limestone.

Garnet crystals often contain inclusions of foreign matter, but only in part due to alteration; as, vesuvianite, calcite, epidote, quartz (Fig. 486, p. 180); at times the garnet is a mere shell, or perimorph, surrounding a nucleus of another species. A black garnet from Arendal, Norway, contains both calcite and epidote; crystals from Tvedestrand, Norway, are wholly calcite within, there being but a thin crust of garnet. Crystals from East Woodstock, Me., are dodecahedrons with a thin shell of cinnamon-stone enclosing calcite; others from Raymond, Me., show successive layers of garnet and calcite. Many such cases have been noted.

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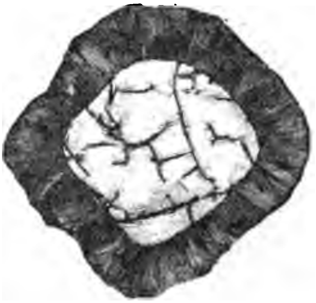


Garnets are often altered, thus to chlorite, serpentine; even to limonite. Crystals of pyrope are sometimes surrounded by a chloritic zone (kelyphite of Schrauf) not homogeneous, as shown in Fig. 847.

Among prominent foreign localities of garnets, besides those already mentioned, are the following — GROSSULARITE: Fine *cinnamon-stone* comes from Ceylon; on the Mussa-Alp in the Ala valley in Piedmont, Italy, with clinochlore and diopside; at Zermatt, Switzerland; pale yellow at Auerbach, Germany; brownish (*romanzovite*) at Kimito in Finland; honey-yellow *octahedrons* in Elba; pale greenish from the banks of the Vilui in Siberia, in serpentine with vesuvianite; also from Cziklowa and Orawitza in the Banat, Hungary; with vesuvianite and wollastonite in ejected masses at Vesuvius; in white or colorless crystals in Tellemark, in Norway; also dark brown at Mudgee, New South Wales; dark honey-yellow at Guadalcazar, and clear pink or rose-red dodecahedrons at Xalostoc, Morelos, Mexico, called variously, *landerite*, *xalostocite* and *rosolite*.

PYROPE: In serpentine (from peridotite) near Meronitz and the valley of Krems, in Bohemia (used as a gem); at Zöblitz in Saxony; in the Vosges Mts.; in the diamond diggings of South Africa ("Cape rubies"). ALMANDITE: Common in granite, gneiss, eclogite, etc., in many localities in Saxony, Silesia, etc.; at Eppenreuth near Hof, Bavaria; in large dodecahedrons at Falun in Sweden; hyacinth-red or brown in the Zillertal, Tyrol, Austria. Precious garnet comes in fine crystals from Ceylon, Pegu, British India, Brazil, and Greenland. SPESSARTITE: From Aschaffenburg in the Spessart, Bavaria; at St. Marcel, Piedmont, Italy; near Chanteloube, Haute Vienne, France, etc.

ANDRADITE: The beautiful green *demantoid* or "Uralian emerald" occurs in transparent greenish rolled pebbles, also in crystals, in the gold washings of Nizhni-Tagilsk in the Ural Mts.; green crystals occur at Schwarzenberg, Saxony; brown to green at Morawitza and Dognacska, Hungary; emerald-green at Dobschau, Hungary; in the Ala valley, Piedmont, Italy, the yellow to greenish *topazolite*. *Allochroite*, apple-green and yellowish, occurs at Zermatt, Switzerland; black crystals (*melanite*), also brown, at Vesuvius on Mte. Somma; near Barèges in the Hautes-Pyrénées, France, (*pyreneite*). *Aplome* occurs at Schwarzenberg in Saxony, in brown to black crystals. Other localities are Pfitschtal, Tyrol, Austria; Långban, Sweden; Pitkäranta, Finland; Arendal, Norway. UVAROVITE: Found at Saranovskaya near Bisersk, also in the vicinity of Kyshtymsk, Ural Mts., in chromic iron; at Jordansmühl, Silesia; Pic Posets near Vénasque in the Pyrenees on chromite.

In North America, in Me., beautiful crystals of cinnamon-stone (with vesuvianite) occur at Parsonsfield, Phippsburg, and Rumford, at Raymond. In N. H., at Hanover, small clear crystals in gneiss; at Warren, cinnamon garnets; at Grafton. In Ver., at New Fane, in chlorite slate. In Mass., in gneiss at Brookfield; in fine dark red or nearly black trapezohedral crystals at Russell, sometimes very large. In Conn., trapezohedrons, in mica slate, at Reading and Monroe; dodecahedrons at Southbury and Roxbury; at Haddam, crystals of spessartite. In N. Y., brown crystals at Crown Point, Essex Co.; colophonite as a large vein at Willsboro, Essex Co.; in Middletown, Delaware Co., large brown crystals; a cinnamon variety at Amity. In N. J., at Franklin, black, brown, yellow, red, and green dodecahedral garnets; also near the Franklin Furnace (*polyadelphite*). In Pa., in Chester Co., at Pennsbury, fine dark brown crystals; near Knauertown; at Chester, brown; in Concord, on Green's Creek, resembling pyrope; in Leiperville, red; at Mineral Hill, fine brown; at Avondale quarry, fine hessonite; uvarovite at Woods' chrome mine, Lancaster Co. In Va., beautiful transparent spessartite, used as a gem, at the mica mines at Amelia Court-House. In N. C., fine cinnamon-stone at Bakersville; red garnets in the gold washings of Burke, McDowell, and Alexander counties; *rhodolite* in Macon Co.; also mined near

Morgantown and Warlich, Burke Co., to be used as "emery," and as "garnet-paper." In Ky., fine pyrope in the peridotite of Ellis Co. In Ark., at Magnet Cove, a titaniferous melanite with schorlomite. Large dodecahedral crystals altered to chlorite occur at the Spurr Mt. iron mine, Lake Superior, Mich. In Col., at Nathrop, fine spessartite crystals in lithophyses in rhyolite; in large dodecahedral crystals at Ruby Mt., Salida, Chaffee Co., the exterior altered to chlorite. In Ariz., yellow-green crystals in the Gila cañon; pyrope on the Colorado river in the western part of the territory. N. M., fine pyrope on the Navajo reservation with chrysolite and a chrome-pyroxene. In Cal., green with copper ore, Hope Valley, El Dorado Co.; uvarovite, in crystals on chromite, at New Idria. Fine crystals of a rich red color and an inch or more in diameter occur in the mica schists at Fort Wrangell, mouth of the Stickeen river, in Alaska.

In Canada, at Marmora, dark red; at Grenville, a cinnamon-stone; an emerald-green chrome-garnet, at Orford, Quebec, with millerite and calcite; fine colorless to pale olive-green, or brownish crystals, at Wakefield, Ottawa Co., Quebec, with white pyroxene, honey-yellow vesuvianite, etc., also others bright green carrying chromium; dark red garnet in the townships of Villeneuve (spessartite) and Templeton; at Hull, Quebec.

Use. — The various colored and transparent garnets are used as semiprecious gem stones. At times the mineral is also used as an abrasive.

Schorlomite. Probably analogous to garnet, $3CaO.(Fe,Ti)_2O_3.3(Si,Ti)O_2$. Usually massive, black, with conchoidal fracture and vitreous luster. H. = 7–7·5. G. = 3·81–3·88. From Magnet Cove, Ark.; in nepheline-syenite on Ice River, British Columbia.

Partschinite. $(Mn,Fe)_3Al_2Si_3O_{12}$ like spessartite. In small dull crystals (monoclinic). H. = 6·5–7. G. = 4·006. Color yellowish, reddish. From the auriferous sands of Oláhpian, Transylvania.

Agricolite. Same as for eulytite, $Bi_4Si_3O_{12}$, but monoclinic. In globular or semi-globular forms. From Johanngeorgenstadt, Germany.

Chrysolite Group. R_2SiO_4. Orthorhombic

		mm'''	hh'	
		$110 \wedge 1\bar{1}0$	$011 \wedge 0\bar{1}1$	$a : b : c$
Monticellite	$CaMgSiO_4$	46° 54′	59° 52′	0·4337 : 1 : 0·5758
Forsterite	Mg_2SiO_4	49° 51′	60° 43′	0·4648 : 1 : 0·5857
Chrysolite	$(Mg,Fe)_2SiO_4$	49° 57′	60° 47′	0·4656 : 1 : 0·5865
Hortonolite	$(Fe,Mg,Mn)_2SiO_4$			
Fayalite	Fe_2SiO_4	49° 15′	60° 10′	0·4584 : 1 : 0·5793
Knebelite	$(Fe,Mn)_2SiO_4$			
Tephroite	Mn_2SiO_4	49° 24′	61° 25′	0·4600 : 1 : 0·5939

The CHRYSOLITE GROUP includes a series of orthosilicates of magnesium, calcium, iron and manganese. They all crystallize in the orthorhombic system with but little variation in axial ratio. The prismatic angle is about 50°, and that of the unit brachydome about 60°; corresponding to the latter threefold twins are observed. The type species is chrysolite (or olivine), which contains both magnesium and iron in varying proportions and is hence intermediate between the comparatively rare magnesium and iron silicates.

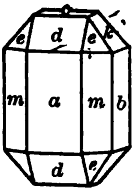
In form, the species of the Chrysolite Group, R_2SiO_4, are closely related in angle to Chrysoberyl, $BeAl_2O_4$; also somewhat less closely to the species of the Diaspore Group, $H_2Al_2O_4$, etc. There is also an interesting relation between the chrysolites and the humites (see p. 535).

CHRYSOLITE. Olivine. Peridot.

Orthorhombic. Axes $a : b : c = 0{\cdot}46575 : 1 : 0{\cdot}5865$.

mm‴, 110 ∧ $1\bar{1}0$ = 49° 57′.
ss′, 120 ∧ $\bar{1}20$ = 94° 4′.
dd′, 101 ∧ $\bar{1}01$ = 103° 6′.
kk, 021 ∧ $0\bar{2}1$ = 99° 6′.
ee‴, 111 ∧ $1\bar{1}1$ = 40° 5′.
ff‴, 121 ∧ $1\bar{2}1$ = 72° 13′.

848



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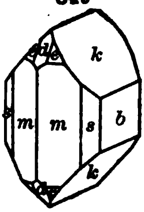


Twins rare: tw. pl. *h* (011) with angle between basal planes of the two individuals = 60° 47′, penetration-twins, sometimes repeated; tw. pl. *w* (012), the vertical axes crossing at an angle of about 30°. Crystals often flattened ‖ *a* (100) or *b* (010), less commonly elongated ‖ *c* axis. Massive, compact, or granular; in embedded grains.

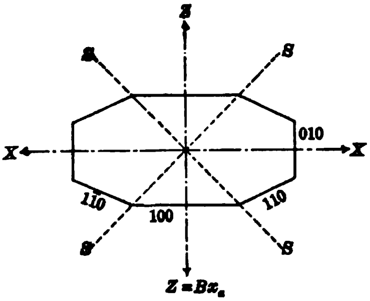
Cleavage: *b* (010) rather distinct; *a* (100) less so. Fracture conchoidal. Brittle. H. = 6·5–7. G. = 3·27–3·37, increasing with the amount of iron; 3·57 for hyalosiderite (30 p. c. FeO). Luster vitreous. Color green — commonly olive-green, sometimes brownish, grayish red, grayish green, becoming yellowish brown or red by oxidation of the iron. Streak usually uncolored, rarely yellowish. Transparent to translucent. Optically +. Ax. pl. ‖ *c* (001), Bx ⊥ *a* (100). Dispersion $\rho < v$, weak. Axial angle large. $\alpha = 1{\cdot}662$. $\beta = 1{\cdot}680$. $\gamma = 1{\cdot}699$.

Var. — *Precious.* — Of a pale yellowish green color, and transparent. G. = 3·441, 3·351. Occasionally seen in masses as large as "a turkey's egg," but usually much smaller. It has long been brought from the Levant for jewelry, but the exact locality is not known.

Common; Olivine. — Dark yellowish green to olive- or bottle-green. G. = 3·26–3·40. Disseminated in crystals or grains in basic igneous rocks, basalt and basaltic lavas, etc. *Hyalosiderite* is a highly ferruginous variety.

Comp. — $(Mg,Fe)_2SiO_4$ or $2(Mg,Fe)O.SiO_2$. The ratio of Mg : Fe varies widely, from 16 : 1, 12 : 1, etc., to 2 : 1 in hyalosiderite, and hence passing from forsterite on the one side to fayalite on the other. No sharp line can be drawn on either side. Titanium dioxide is sometimes present replacing silica; also tin and nickel in minute quantities.

850



Pyr., etc. — B.B. whitens, but is infusible in most cases; hyalosiderite and other varieties rich in iron fuse to a black magnetic globule; some kinds turn red upon heating. With the fluxes gives reactions for iron. Some varieties give reactions for titanium and manganese. Soluble in hydrochloric acid and yields gelatinous silica upon evaporation.

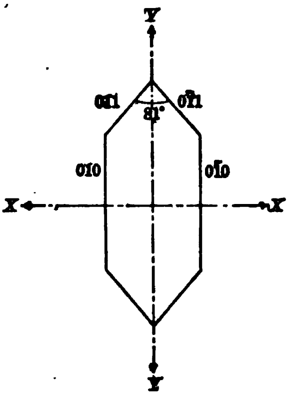
Diff. — Characterized by its infusibility, the yellow-green color, granular form and cleavage (quartz has none).

Micro. — Recognized in thin sections by its high relief: lack of color; its few but marked rough cleavage-cracks; high interference-colors, which are usually the brilliant and pronounced tones of the second order; parallel extinction; biaxial character; characteristic outlines (usually with acute terminations) when in distinct crystals (Figs. 850–852), its frequent association with iron ore and augite, and its very common alteration, in a greater or less degree, to serpentine, the first stages being marked by the separation of iron-ore grains along the lines of fracture (Fig. 853).

Artif. — The different members of the Chrysolite Group have been easily synthesized in various ways. They are often observed in slags.

Obs. — Chrysolite (olivine) has two distinct methods of occurrence: (*a*) in igneous rocks, as peridotite, norite, basalt, diabase and gabbro, formed by the crystallization of magmas low in silica and rich in magnesia; from an accessory component in such rocks the olivine may increase in amount until it is the main rock constituent as in the dunites; also (*b*) as the product of metamorphism of certain sedimentary rocks containing magnesia and silica, as in impure dolomites. In the dunites and peridotites of igneous origin the chrysolite is commonly associated with chromite, spinel, pyrope, etc., which are valuable indications also of the origin of serpentines derived from olivine. In the metamorphic rocks the above are wanting, and carbonates, as dolomite, breunnerite, magnesite, etc., are the common associations; chrysolitic rocks of this latter kind may also occur altered to serpentine.

851



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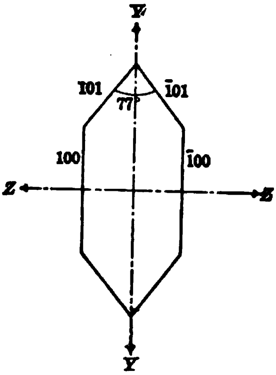

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Chrysolite also occurs in grains, rarely crystals, embedded in some meteoric irons. Also present in meteoric stones, frequently in spherical forms, or chondrules, sometimes made up of a multitude of grains with like (or unlike) optical orientation enclosing glass between.

Among the more prominent localities are: Vesuvius in lava and on Monte Somma in ejected masses, with augite, mica, etc. In Germany observed in the so called sanidine bombs at the Laacher See; at Forstberg near Mayen in the Eifel and forming the mass of "olivine bombs" in the Dreiser Weiher near Daun in the same region; at Sasbach in the Kaiserstuhl, Baden (*hyalosiderite*). In crystals of gem-quality from Egypt. In Sweden, with ore-deposits, as at Långban, Pajsberg, Persberg, etc. In serpentine at Snarum, Norway, in large crystals, themselves altered to the same mineral. Common in the volcanic rocks of Sicily, the Hawaiian Islands, the Azores, etc.

In the United States, in Thetford and Norwich, Ver., in boulders of coarsely crystallized basalt, the crystals or masses several inches through. In olivine-gabbro of Waterville, in the White Mts., N. H.; at Webster, in Jackson Co., N. C., with serpentine and chromite; with chromite in Loudon Co., Va.; in Lancaster Co., Pa. In small clear olive-green grains with garnet at some points in Ariz. and N. M. In basalt in Canada, near Montreal, at Rougemont and Mounts Royal and Montarville, and in eruptive rocks at other points.

Alteration of chrysolite often takes place through the oxidation of the iron; the mineral becomes brownish or reddish brown and iridescent. The process may end in leaving the cavity of the crystal filled with limonite or red oxide of iron. A very common kind of alteration is to the hydrous magnesium silicate, serpentine, with the partial removal of the iron or its separation in the form of grains of magnetite, also as iron sesquioxide; this change has often taken place on a large scale. See further under serpentine, p. 573.

Chrysolite is named from χρυσός, *gold*, and λίθος. The hyalosiderite, from ὕαλος, *glass*, and σίδηρος, *iron*. The *chrysolithus* of Pliny was probably our topaz; and his *topaz* our *chrysolite*.

Use. — The clear, fine green varieties are used as a gem stone; usually called *peridot*.

IDDINGSITE. From the rock carmeloite of Carmelo Bay, Cal.; a silicate resembling an altered chrysolite, exact composition undetermined. Has been noted as a pseudomorph after chrysolite in a basalt from the Mittelgebirge, Bohemia. Orthorhombic, foliated and cleavable. G. = 2·839. Color brown.

The axial ratios of the other members of the Chrysolite Group are given in the table on p. 510. The species are briefly characterized as follows:

Monticellite. $CaMgSiO_4$. Occurs in colorless to gray crystals on Mte. Somma, Vesuvius; in masses (*batrachite*) on Mt. Monzoni, Tyrol, Italy; in crystals or grains in limestone at Magnet Cove, Ark. G. = 3·03–3·25. Optically –. Indices, 1·651–1·668.

Glaucochroite. $CaMnSiO_4$. In embedded prismatic crystals. Crystal constants and optical properties near those of Chrysolite Group. Color, delicate bluish green. Found at Franklin Furnace, N. J. H. = 6. G. = 3·4.

Forsterite. Mg_2SiO_4. Occurs in white crystals at Vesuvius; in greenish or yellowish embedded grains at Bolton, Mass. (*boltonite*). G. = 3·21–3·33. Optically +. β = 1·659.

Hortonolite. $(Fe,Mg,Mn)_2SiO_4$. In rough dark-colored crystals or masses. Occurs at the iron mine of Monroe, Orange Co., N. Y.; Iron Mine Hill, Cumberland, R. I. G. = 3·91. Optically –. Indices, 1·768–1·803.

Fayalite. Fe_2SiO_4. From the Mourne Mts., Ireland; the Azores; the Yellowstone Park; Rockport, Mass., etc. From Cuddia Mida, Island of Pantelleria, Italy. Crystals and massive, brown to black on exposure. G. = 4·1 Optically –. Indices, 1·824–1·874. *Manganfayalite* is a manganese variety found at Södermanland, Sweden.

Knebelite. $(Fe,Mn)_2SiO_4$. From Dannemora, and elsewhere in Sweden. G. = 4·1.

Tephroite. Mn_2SiO_4; also with zinc, in the variety *roepperite*. From Sterling Hill and Franklin Furnace, N. J.; also from Sweden; from Benderneer, New South Wales. Color flesh-red to ash-gray. G. = 4·1. Optically –. Index about 1·80.

Phenacite Group. R_2SiO_4. Tri-rhombohedral

		rr'	c
Willemite	Zn_2SiO_4	64° 30′	0·6775
Troostite	$(Zn,Mn)_2SiO_4$		
Phenacite	Be_2SiO_4	63° 24′	0·6611

The PHENACITE GROUP includes the above orthosilicates of zinc (manganese) and beryllium. Both belong to the tri-rhombohedral class of the trigonal division of the hexagonal system, and have nearly the same rhombohedral angle. The rare species trimerite, $MnSiO_4.BeSiO_4$, which is pseudohexagonal (triclinic) is probably to be regarded as connecting this group with the preceding Chrysolite Group.

The following rare species are related:

			rr'	c
Dioptase	H_2CuSiO_4	Tri-rhombohedral	54° 5′	0·5342
Friedelite	$H_7(MnCl)Mn_4(SiO_4)_4$		56° 17′	0·5624
Pyrosmalite	$H_7((Fe,Mn)Cl)(Fe,Mn)_4(SiO_4)_4$		53° 49′	0·5308

These species are very near to each other in form, as shown in the above axial ratios; they further approximate to the species of the Phenacite Group proper. They are also closely related among themselves in composition, since they are all acid orthosilicates, and have the general formula $H_2RSiC_4 = H_8R_4(SiO_4)_4$, where (*e.g.* for Friedelite) in the latter form the place of one hydrogen atom is taken by the univalent radical (MnCl).

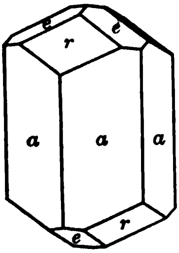
WILLEMITE.

Tri-rhombohedral. Axis c = 0·6775; rr' $(10\bar{1}1) \wedge (\bar{1}101)$ = 64° 30′; ee' $(01\bar{1}2) \wedge (\bar{1}012)$ = 36° 47′.

In hexagonal prisms, sometimes long and slender, again short and stout; rarely showing subordinate faces distributed according to the phenacite type. Also massive and in disseminated grains; fibrous.

Cleavage: c (0001) easy, Moresnet; difficult, N. J.; a $(11\bar{2}0)$ easy, N. J. Fracture conchoidal to uneven. Brittle. H. = 5·5. G. = 3·89–4·18. Luster vitreo-resinous, rather weak. Color white or greenish yellow, when purest; apple-green, flesh-red, grayish white, yellowish brown· often dark brown when impure. Streak uncolored. Transparent to opaque. Optically +. $\omega = 1{\cdot}693$. $\epsilon = 1{\cdot}712$.

854



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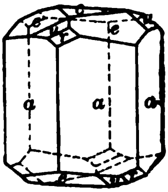

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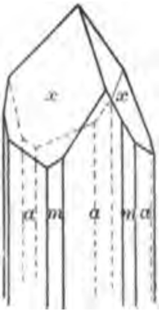

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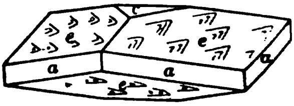


Colorado

Figs. 854–857, New Jersey. e $(0\bar{1}12)$, s $(11\bar{2}3)$, u $(2\bar{1}\bar{1}3)$, x $(3\bar{1}\bar{2}1)$.

Comp. — Zinc orthosilicate, Zn_2SiO_4 or $2ZnO.SiO_2$ = Silica 27·0, zinc oxide 73·0 = 100. Manganese often replaces a considerable part of the zinc (in *troostite*), and iron is also present in small amount.

Pyr., etc. — B.B. in the forceps glows and fuses with difficulty to a white enamel; the varieties from New Jersey fuse from 3·5 to 4. The powdered mineral on charcoal in R.F. gives a coating, yellow while hot and white on cooling, which, moistened with solution of cobalt, and treated in O.F., is colored bright green. With soda the coating is more readily obtained. Soluble in hydrochloric acid and yields gelatinous silica upon evaporation.

Obs. — From Altenberg near Moresnet, Belgium; at Stolberg, near Aix-la-Chapelle. From Musartut, Greenland; Mindouli, French Congo; Kristiania, Norway. In N. J. at Mine Hill, Franklin Furnace, and at Sterling Hill, two miles distant. Occurs with zincite and franklinite, varying in color from white to pale honey-yellow and light green to dark ash-gray and flesh-red; sometimes in large reddish crystals (*troostite*). Rare at the Merritt mine, Socorro Co., N. M.; also at the Sedalia mine, Salida, Col. Named by Lévy after William I., King of the Netherlands.

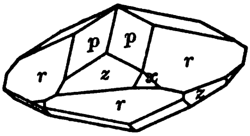
Use. — An ore of zinc.

PHENACITE.

Tri-rhombohedral. Axis $c = 0{\cdot}6611$; rr' $(10\bar{1}1) \wedge (\bar{1}101) = 63° 24'$.

Crystals commonly rhombohedral in habit, often lenticular in form, the prisms wanting; also prismatic, sometimes terminated by the rhombohedron of the third series, x (see further, pp. 110–112).

858



Miask.

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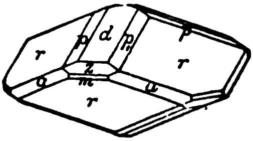
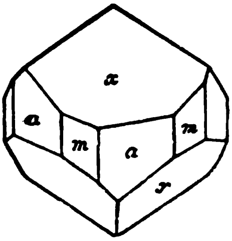


Florissant, Col.

860



Mt. Antero, Col., Pfd.

Cleavage: *a* $(11\bar{2}0)$ distinct; *r* $(10\bar{1}1)$ imperfect. Fracture conchoidal. Brittle. H. = 7·5–8. G. = 2·97–3·00. Luster vitreous. Colorless; also bright wine-yellow, pale rose-red; brown. Transparent to subtranslucent. Optically +. $\omega = 1·6540$; $\epsilon = 1·6697$.

Comp. — Beryllium orthosilicate, Be_2SiO_4 or $2BeO.SiO_2$ = Silica 54·45, glucina 45·55 = 100.

Pyr., etc. — Alone remains unaltered; with borax fuses with extreme slowness, unless pulverized, to a transparent glass. With soda affords a white enamel; with more, intumesces and becomes infusible. Dull blue with cobalt solution.

Obs. — Occurs at the emerald and chrysoberyl mine of Takovaya, 85 versts east of Ekaterinburg, Ural Mts.; also in the Ilmen Mts., near Miask, Russia; near Framont in the Vosges Mts.; Kragerö, Norway; at the Cerro del Mercado, Durango, Mexico; crystals from San Miguel di Piracicaba, Minas Geraes, Brazil.

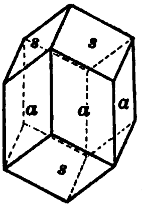
In Col., on amazon-stone, at Topaz Butte, near Florissant, 16 miles from Pike's Peak; also on quartz and beryl at Mt. Antero, Chaffee county. Occurs at Chatham, N. H. Named from φέναξ, *a deceiver*, in allusion to its having been mistaken for quartz.

Trimerite. $(Mn,Ca)_2SiO_4.Be_2SiO_4$. In thick tabular prismatic crystals, pseudohexagonal (triclinic) in form and angle. H. = 6–7. G. = 3·474. Color salmon-pink to nearly colorless in small crystals. Optically −. Indices, 1·715–1·725. From the Harstig mine, Wermland, Sweden.

Dioptase. H_2CuSiO_4 or $H_2O.CuO.SiO_2$. Commonly in prismatic crystals (*ss'* $02\bar{2}1 \wedge \bar{2}021 = 84° 33\frac{1}{2}'$). Also in crystalline aggregates; massive. Cleavage: *r* $(10\bar{1}1)$ perfect. Fracture conchoidal to uneven. H. = 5. G. = 3·28–3·35. Luster vitreous. Color emerald-green. Optically +. $\omega = 1·654$. $\epsilon = 1·707$.

Occurs in druses of well-defined crystals on quartz, occupying seams in a compact limestone west of the hill of Altyn-Tübe in the Kirghiz Steppe, Russia; in the gold washings at several points in Siberia; at Rezbánya, Hungary. From Copiapo, Chile, on quartz with other copper ores. In fine crystals at the Mine Mindouli, two leagues east of Comba, in the French Congo State. Also at the copper mines of Clifton, Graham Co., and from Metcalfe and near Florence, Ariz.

861



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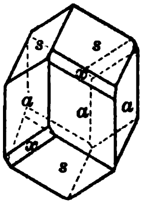


Planchéite. $H_2Cu_7(Cu.OH)_8(SiO_3)_{12}$. Fibrous, often mammillary. Blue color. G. = 3·4. Found associated with dioptase, etc., at Mindouli, French Congo.

Friedelite. $H_7(MnCl)Mn_4Si_4O_{16}$. Crystals commonly tabular ‖ *c* (0001); also massive, cleavable to closely compact. H. = 4–5. G. = 3·07. Color rose-red. From the manganese mine of Adervielle, vallée du Louron, Hautes Pyrénées, France; from Sjö mine, Wermland, Sweden; from Franklin Furnace, N. J.

Pyrosmalite. $H_7((Fe,Mn)Cl)(Fe,Mn)_4Si_4O_{16}$. Crystals thick hexagonal prisms or tabular; also massive, foliated. H. = 4–4·5. G. = 3·06–3·19. Color blackish green to pale liver-brown or gray. Index about 1·66. From the iron mines of Nordmark in Wermland and at Dannemora, Sweden.

Scapolite Group. Tetragonal-pyramidal

Meionite	$c = 0·4393$	**Mizzonite,** Dipyre	$c = 0·4424$
Wernerite	$c = 0·4384$	**Marialite**	$c = 0·4417$

The species of the Scapolite Group crystallize in the pyramidal class of the tetragonal system with nearly the same axial ratio. They are white or grayish white in color, except when impure, and then rarely of dark color.

Hardness = 5–6·5; G. = 2·5–2·8. In composition they are silicates of aluminium with calcium and sodium in varying amounts; chlorine is also often present, sometimes only in traces. Iron, magnesia, potash are not present unless by reason of inclusions or of alteration. Carbon dioxide and sulphur trioxide have been noted in certain analyses. It has been suggested that these radicals enter into the composition in the same manner as the chlorine.

The Scapolites are analogous to the Feldspars in that they form a series with a gradual variation in composition, the amount of silica increasing with the increase of the alkali, soda, being 40 p. c. in meionite and 64 p. c. in marialite. A corresponding increase is observed also in the amount of chlorine present. Furthermore there is also a gradual change in specific gravity, in the strength of the double refraction, and in resistance to acids, from the easily decomposed meionite, with G. = 2·72, to marialite, which is only slightly attacked and has G. = 2·63. Tschermak has shown that the variation in composition may be explained by the assumption of two fundamental end compounds, viz.:

Meionite	$Ca_4Al_6Si_6O_{25}$	Me
Marialite	$Na_4Al_3Si_9O_{24}Cl$	Ma

By the isomorphous combination of these compounds the composition of the species mentioned above may be explained; no sharp line can, however, be drawn between them.

Optically the series is characterized by the decrease in the strength of the double refraction in passing from meionite to marialite. Thus (Lacroix) for meionite $\omega - \epsilon = 0·036$; for typical wernerite 0·03–0·02; for dipyre 0·015.

The tetragonal species melilite and gehlenite are near the Scapolites in angle. The more common vesuvianite is also related.

MEIONITE.

Tetragonal. Axis $c = 0·43925$. In prismatic crystals (Fig. 201, p. 86), either clear and glassy or milky white; also in crystalline grains and massive. Cleavage: *a* (100) rather perfect, *m* (110) somewhat less so. Fracture conchoidal. Brittle. H. = 5·5–6 G. = 2·70–2·74. Luster vitreous. Colorless to white. Transparent to translucent; often cracked within. Optically −. $\omega = 1·597$; $\epsilon = 1·560$.

Comp. — $Ca_4Al_6Si_6O_{25}$ or $4CaO.3Al_2O_3.6SiO_2$ = Silica 40·5, alumina 34·4, lime 25·1 = 100.

The varieties included here range from nearly pure meionite to those consisting of meionite and marialite in the ratio of 3 : 1, *i.e.*, Me : Ma = 3 : 1. No sharp line can be drawn between meionite and the following species.

Obs. — Occurs in small crystals in cavities, usually in limestone blocks, on Monte Somma, Vesuvius. Also in ejected masses at the Laacher See, Germany. A mineral in an amphibole-gneiss from the Black Forest, Germany, which is like meionite except for a basal cleavage has been called *pseudomeionite*.

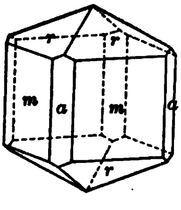
WERNERITE. COMMON SCAPOLITE.

Tetragonal-pyramidal. Axis $c = 0·4384$.

Crystals prismatic, usually coarse, with uneven faces and often large. The symmetry of the pyramidal class sometimes shown in the development of the faces z (311) and z_1 (131). Also massive, granular, or with a faint fibrous appearance; sometimes columnar.

ee′, 101 ∧ 011 = 32° 59′.
rr′, 111 ∧ 1̄11 = 43° 45′.
mr, 110 ∧ 111 = 58° 12′.
zz‴, 311 ∧ 311 = 29° 43′.

863



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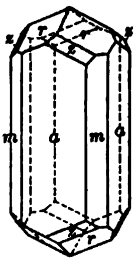


Cleavage: *a* (100) and *m* (110) rather distinct, but interrupted. Fracture subconchoidal. Brittle. H. = 5–6. G. = 2·66–2·73. Luster vitreous to pearly externally, inclining to resinous; cleavage and cross-fracture surface vitreous. Color white, gray, bluish, greenish, and reddish, usually light; streak uncolored. Transparent to faintly subtranslucent. Optically –. $\omega = 1{\cdot}570$. $\epsilon = 1{\cdot}549$.

Comp. — Intermediate between meionite and marialite and corresponding to a molecular combination of these in a ratio 3 : 1 to 1 : 2. The silica varies from 46 to 54 p.c., and as its amount increases the soda and chlorine also increase. Scapolites with silica from 54 p. c. to 60 p. c. are classed with mizzonite; they correspond to Me : Ma from 1 : 2 to 1 : 3 and upwards.

The percentage composition for a common compound is as follows:

Me : Ma 3 : 1 SiO_2 46·10 Al_2O_3 30·48 CaO 19·10 Na_2O 3·54 Cl 1·01 = 100·23

Pyr., etc. — B.B. fuses easily with intumescence to a white blebby glass giving a strong sodium flame color. Imperfectly decomposed by hydrochloric acid.

Diff. — Characterized by its square form and prismatic cleavage (90°); resembles feldspar when massive, but has a characteristic fibrous appearance on the cleavage surface; it is also more fusible, and has a higher specific gravity; also distinguished by fusibility with intumescence from pyroxene (which see, p. 478).

Micro. — Recognized in thin sections by its low refraction; lack of color; rather high interference-colors reaching the yellows and reds of the first order, sections showing which extinguish parallel to the cleavage; by the distinct negative axial cross of basal sections which show the cleavage-cracks crossing at right angles.

Obs. — Occurs in metamorphic rocks, crystalline schists, gneisses, amphibolites and most abundantly in granular limestone near its junction with the associated granitic or allied rocks; sometimes in beds of magnetite accompanying limestone. It is often associated with a light-colored pyroxene, amphibole, garnet, and also with apatite, titanite, zircon; amphibole is a less common associate than pyroxene, but in some cases has resulted from the alteration of pyroxene. Scapolite has been shown also to be frequently a component of basic igneous rocks, especially those rich in plagioclases containing much lime; it is regarded as a secondary product through a certain kind of alteration. The scapolites are easily altered; pseudormorphs of mica, more rarely other minerals, are common.

Prominent localities are at Pargas, Finland, where it occurs in limestone; Arendal in Norway, and Malsjö in Wermland, Sweden, where it occurs with magnetite in limestone. *Passauite* is from Obernzell, near Passau, in Bavaria. The pale blue or gray scapolite from Lake Baikal, Siberia, is called *glaucolite*. In the United States, occurs in Ver., at Marlborough, massive. In Mass., at Bolton; at Chelmsford. In N. Y. in Orange Co., Essex Co., Lewis Co.; Grasse Lake, Jefferson Co.; at Gouverneur, in limestone. In N. J., at Franklin and Newton. In Pa., at the Elizabeth mine, French Creek, Chester Co.

In Canada, at Calumet Island, massive; at Grenville; Templeton; Wakefield, Ottawa Co.; at Bedford and Bathurst, Ont : Scapolite rocks occur at several points.

Mizzonite. Dipyre. Here are included scapolites with 54 to 57 p. c. SiO_2, corresponding to a molecular combination from Me : Ma = 1 : 2 to Me : Ma = 1 : 3. *Mizzonite* occurs in clear crystals in ejected masses on Mte. Somma, Vesuvius.

Dipyre occurs in elongated square prisms, often slender, sometimes large and coarse, in limestone and crystalline schists, chiefly from the Pyrenees; also in diorite at Bamle, Norway; Saint-Nazaire, France; Algeria. *Couseranite* from the Pyrenees is a more or less altered form of dipyre.

Marialite. Theoretically $Na_4Al_3Si_9O_{24}Cl$, see p. 516. Indices, 1·541–1·554. The actual mineral corresponds to Me : Ma = 1 : 4. It occurs in a basalt tuff, at Pianura, near Naples.

Sarcolite. $(Ca,Na_2)_3Al_2(SiO_4)_3$. In small tetragonal crystals. H. = 6. G. = 2·545–2·932. Color flesh-red. Indices, 1·640–1·656. From Monte Somma, Vesuvius.

MELILITE.

Tetragonal. Axis c = 0·4548. Usually in short square prisms (a (100)) or octagonal prisms (a, m (110)), also in tetragonal tables.

Cleavage: c (001) distinct; a (100) indistinct. Fracture conchoidal to uneven. Brittle. H. = 5. G. = 2·9–3·10. Luster vitreous, inclining to resinous. Color white, pale yellow, greenish, reddish, brown. Pleochroism distinct in yellow varieties. Sometimes exhibits optical anomalies. Optically –. $\omega = 1·634$. $\epsilon = 1·629$.

Comp. — Perhaps $\overset{II}{R}_{12}\overset{III}{R}_4Si_9O_{36}$ or $Na_2(Ca,Mg)_{11}(Al,Fe)_4(SiO_4)_9$ for melilite. If Ca : Mg = 8 : 3, and Al : Fe = 1 : 1, the percentage composition is: Silica 37·7, alumina 7·1, iron sesquioxide 11·2, lime 31·3, magnesia 8·4, soda 4·3 = 100. Potassium is also present.

The composition of the melilite-gehlenite group can be explained as isomorphous mixtures of the three compounds, *sarcolite*, $3CaO.Al_2O_3.3SiO_2$ or *soda-sarcolite* $3Na_2O.Al_2O_3.3SiO_2$; *åkermanite*, $8CaO.4MgO.9SiO_2$; velardeñite, $2CaO.Al_2O_3.SiO_2$. The last is noted in large amount in gehlenite from the Velardeña mining district, Mexico.

Artif. — Melilite has been formed artificially by fusing together its constituent oxides. It is found in slags and has been produced in various artificial magmas.

Pyr., etc. — B.B. fuses at 3 to a yellowish or greenish glass. With the fluxes reacts for iron. Soluble in hydrochloric acid and yields gelatinous silica upon evaporation.

Micro. — Distinguished in thin sections by its moderate refraction; very low interference-colors, showing often the "*ultra blue*" (Capo di Bove); parallel extinction; negative character; usual development in tables parallel to the base and very common "peg structure" due to parallel rod-like inclusions penetrating the crystal from the basal planes inward: this, however, is not always easily seen.

Obs. — Melilite is a component of certain igneous rocks formed from magmas very low in silica, rather deficient in alkalies, and containing considerable lime and alumina. In such cases melilite appears to crystallize in the place of the more acid plagioclase.

Melilite of yellow and brownish colors is found at Capo di Bove, near Rome; in leucitophyre with nephelite, augite, hornblende; at Vesuvius in dull yellow crystals (*somervillite*); not uncommon in certain basic eruptive rocks, as the *melilite-basalts* of Hochbohl near Owen in Württemberg, of the Swabian Alp, of Görlitz, the Erzgebirge, Germany; also in the nephelite basalts of the Hegau, of Oahu, Hawaiian Islands, etc.; perovskite is a common associate. Occurs as chief constituent of rock on Beaver Creek, Gunnison Co., Col. Common in furnace slags. Melilite is named from *μέλι*, *honey*, in allusion to the color.

Humboldtilite occurs in cavernous blocks on Monte Somma, Vesuvius, with greenish mica, also apatite, augite; the crystals are often rather large, and covered with a calcareous coating; less common in transparent lustrous crystals with nephelite, sarcolite, etc., in an augitic rock. *Zurlite* is impure humboldtilite. *Deeckeite* is a pseudomorph after *melilite* with the composition $(H,K,Na)_2(Mg,Ca)(Al,Fe)_2(Si_2O_5)_5.9H_2O$, found in a melilite basalt from the Kaiserstuhl, Baden, Germany.

Cebollite. $H_2Ca_5Al_2Si_3O_{16}$. Orthorhombic (?). Fibrous. H. = 5. G. = 2·96. Color white to greenish gray. Indices, 1·59–1·63. Fusible at 5. Soluble in acids. Found as an alteration product of *melilite* near Cebolla Creek, Gunnison Co., Col.

Gehlenite. $Ca_3Al_2Si_2O_{10}$. Crystals usually short square prisms. Axis c = 0·4001. G. = 2·9–3·07. Different shades of grayish green to liver-brown. From Mount Monzoni, in the Fassatal, in Tyrol, Austria. From Velardeña mining district, Mexico.

FUGGERITE Corresponds to a member of the gehlenite-åkermanite series, 3 åk : 10 geh. From Monzonite of Monzonital, Tyrol, Austria.

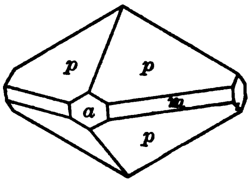
Åkermanite. Tetragonal, isomorphous with melilite and gehlenite. Found in certain slags. See further under Melilite.

VESUVIANITE. Idocrase.

Tetragonal. Axis $c = 0{\cdot}5372$.

ce, 001 ∧ 101 = 28° 15′.
cp, 001 ∧ 111 = 37° 13½′.
ct, 001 ∧ 331 = 66° 18′.
pp′, 111 ∧ $\bar{1}$11 = 50° 39′.
ss$^{\text{vii}}$, 311 ∧ 3$\bar{1}$1 = 31° 38′.

865



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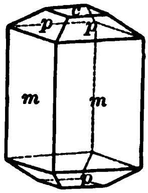

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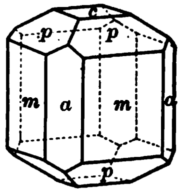

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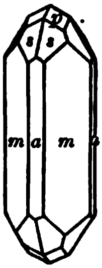

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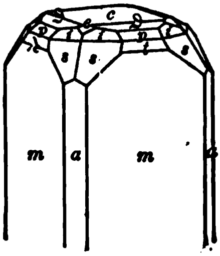

Zermatt

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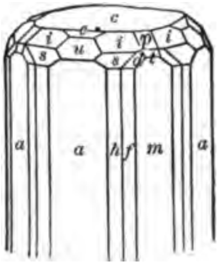


Sandford, Me.

Often in crystals, prismatic or pyramidal. Also massive; columnar, straight and divergent, or irregular; granular massive; cryptocrystalline.

Cleavage: *m* (110) not very distinct; *a* (100) and *c* (001) still less so. Fracture subconchoidal to uneven. Brittle. H. = 6·5. G. = 3·35–3·45. Luster vitreous; often inclining to resinous. Color brown to green, and the latter frequently bright and clear; occasionally sulphur-yellow, and also pale blue. Streak white. Subtransparent to faintly subtranslucent. Dichroism not usually strong. Optically −; also + rarely. Birefringence very low. Sometimes abnormally biaxial. Indices variable, from 1·715 to 1·720.

Comp. — A basic calcium-aluminium silicate, but of uncertain formula; perhaps $Ca_6[Al(OH,F)]Al_2(SiO_4)_5$. Ferric iron replaces part of the aluminium and magnesium the calcium. Fluorine and titanium may be present. Another general formula has been proposed, $\overset{\text{I}}{R}_4Ca_7Al_2Si_6O_{24}$, in which $\overset{\text{I}}{R}_4$ may be $Ca_2,(AlOH)_2,(AlO_2H)_4$, or H_4.

Pyr., etc. — B.B. fuses at 3 with intumescence to a greenish or brownish glass. With the fluxes gives reactions for iron, and some varieties a strong manganese reaction. *Cyprine*, a blue variety, gives a reaction for copper with salt of phosphorus. Partially decomposed by hydrochloric acid, and completely when the mineral has been previously ignited.

Diff. — Characterized by its tetragonal form and easy fusibility. Resembles some brown varieties of garnet, tourmaline, and epidote.

Micro. — Recognized in thin sections by its high refraction producing a very strong relief and its extremely low birefringence;* also in general by its color, pleochroism, and uniaxial negative character; the latter, on account of the low birefringence, being difficult to determine. The low birefringence, however, aids in distinguishing it from epidote, with which at times it may be confounded.

Obs. — Vesuvianite was first found among the ancient ejections of Vesuvius and the dolomitic blocks of Monte Somma, whence its name. It commonly occurs as a contact mineral from the alteration of impure limestones, then usually associated with lime garnet (grossularite), phlogopite, diopside, wollastonite; also epidote; also in serpentine, chlorite schist, gneiss and related rocks.

Prominent localities are Vesuvius; the Albani Mts.; in Switzerland at Zermatt, etc.; the Mussa Alp in the Ala valley, in Piedmont, Italy; Mt. Monzoni in the Fassatal, Austria; at Orawitza and Dognaczka, Hungary; Haslau near Eger in Bohemia (*egeran*); near Jordansmühl, Silesia; on the Vilui river, near Lake Baikal, Siberia (sometimes called *wiluite* or viluite, like the grossular garnet from the same region); Achmatovsk, Ural Mts.; in Norway; at Arendal, "*colophonite*"; at Egg, near Christiansand; at Morelos, Mexico.

In North America, in Me. at Phippsburg and Rumford; at Sandford. In N. H., at Warren with cinnamon-stone. In N. Y., near Amity. In N. J., at Newton. In Lewis and Clark Co., Mon. In Cal. near San Carlos in Inyo Co.; at Crestmore, Riverside Co. In Canada, at Calumet Falls, Litchfield, Pontiac Co.; at Grenville in calcite; at Templeton, Ottawa Co., Quebec. A lavender-colored variety, known as *mangan-vesuvianite* comes from near Black Lake, Quebec.

Californite is a closely compact variety of an olive-green to a grass-green color from Siskiyou, Fresno and Tulare Cos., Cal.

Zircon Group. $\overset{\text{IV}}{R}SiO_4$. Tetragonal

Zircon	$ZrSiO_4$	$c = 0{\cdot}6404$
Thorite	$ThSiO_4$	$c = 0{\cdot}6402$

This group includes the orthosilicates of zirconium and thorium, both alike in tetragonal crystallization, axial ratio and crystalline habit.

These species are sometimes regarded as oxides and then included in the RUTILE GROUP (p. 425), to which they approximate closely in form. A similar form belongs also to the tantalate, Tapiolite, and to the phosphate, Xenotime; further, compound groups consisting of crystals of Xenotime and Zircon in parallel position are not uncommon (Fig. 462, p. 173).

ZIRCON.

Tetragonal. Axis $c = 0{\cdot}64037$.

ee', $101 \wedge 011 = 44° 50'$

ee'', $101 \wedge \bar{1}01 = 65° 16'$.

pp', $111 \wedge \bar{1}11 = 56° 40\frac{1}{2}'$.

uu', $331 \wedge \bar{3}31 = 83° 9'$.

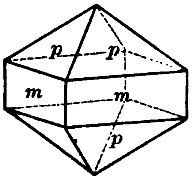
mp $110 \wedge 111 = 47° 50'$.

mu, $110 \wedge 331 = 20° 12\frac{1}{2}'$.

xx^{vii}, $311 \wedge 3\bar{1}1 = 32° 57'$.

ax, $100 \wedge 311 = 31° 43'$.

871



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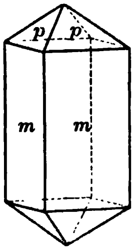

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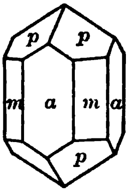

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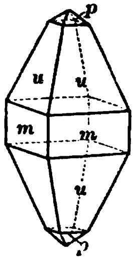

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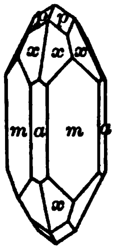
* Frequently minerals, which, like vesuvianite, melilite and zoisite, are doubly refracting but of extremely low birefringence and possibly (where they are positive for one color

Twins: tw. pl. *e* (101), geniculated twins like rutile (Fig. 412, p. 166). Commonly in square prisms, sometimes pyramidal. Also in irregular forms and grains.

875



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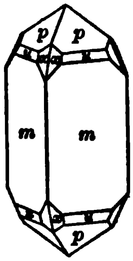

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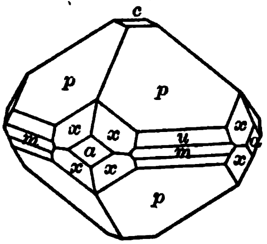

Colorado

Cleavage: *m* (110) imperfect; *p* (111) less distinct. Fracture conchoidal. Brittle. H. = 7·5. G. = 4·68–4·70 most common, but varying widely to 4·2 and 4·86. Luster adamantine. Colorless, pale yellowish, grayish, yellowish green, brownish yellow, reddish brown. Streak uncolored. Transparent to subtranslucent and opaque. Optically +. Birefringence high. $\omega = 1{\cdot}9239$, $\epsilon = 1{\cdot}9682$, Ceylon. Sometimes abnormally biaxial.

Hyacinth is the orange, reddish and brownish transparent kind used for gems. *Jargon* is a name given to the colorless or smoky zircons of Ceylon, in allusion to the fact that while resembling the diamond in luster, they are comparatively worthless; thence came the name *zircon*.

Comp. — $ZrSiO_4$ or $ZrO_2.SiO_2$ = Silica 32·8, zirconia 67·2 = 100. A little iron (Fe_2O_3) is usually present.

Pyr., etc. — Infusible; the colorless varieties are unaltered, the red become colorless, while dark-colored varieties are made white; some varieties glow and increase in density by ignition. Not perceptibly acted upon by salt of phosphorus. In powder decomposed when fused with soda on the platinum wire, and if the product is dissolved in dilute hydrochloric acid it gives the orange color characteristic of zirconia when tested with turmeric paper. Not acted upon by acids except in fine powder with concentrated sulphuric acid. Decomposed by fusion with alkaline carbonates and bisulphates.

Diff. — Characterized by the prevailing square pyramid or square prism; also by its adamantine luster, hardness, high specific gravity, and infusibility; the diamond is optically isotropic.

Micro. — Recognized in thin sections by its very high relief; very high interference-colors, which approach white of the higher order except in very thin sections; positive uniaxial character. It is distinguished from cassiterite and rutile only by its lack of color, and from the latter also in many cases by method of occurrence.

Artif. — Zircon has been prepared artificially by heating zirconium oxide with quartz in gaseous silicon fluoride.

Obs. — A common accessory constituent of igneous rocks, especially those of the more acid feldspathic groups and particularly the kinds derived from magmas containing much soda, as granite, syenite, diorite, etc. It is one of the earliest minerals to crystallize from a cooling magma. Is generally present in minute crystals, but in pegmatitic facies often in large and well-formed crystals. Occurs more rarely elsewhere, as in granular limestone, chloritic and other schists; gneiss; sometimes in iron-ore beds. Crystals are common in most auriferous sands. Sometimes found in volcanic rocks, probably in part as inclusions derived from older rocks.

Zircon in distinct crystals is so common in the pegmatitic forms of the nephelite-syenite

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but negative for another), do not show a gray color between crossed nicols but a curious blue, at times an intense Berlin blue, which is quite distinct from the other blues of the color scale and is known as the "*ultra blue.*"

and augite-syenite of southern Norway (with ægirite, etc.) that this rock there and where has sometimes been called a "zircon-syenite."

Found in alluvial sands in Ceylon; in the gold regions of the Ural Mts.; in Norway Laurvik, at Arendal, in the iron mines, at Fredriksvärn, and in veins in the augite-sy of the Langesund fiord; Pfitschtal, Tyrol, Austria; in Germany in lava at Niedermen the Eifel, red crystals; from Madagascar; from Minas Geraes, Brazil.

In North America, in Me., at Litchfield; in N. Y., in Moriah, Essex Co., cinnam red; near the outlet of Two Ponds, Orange Co., with scapolite, pyroxene and titanit Warwick, chocolate-brown, near Amity; in St. Lawrence Co., in the town of Hamm at Rossie, Fine, Pitcairn. In Pa., near Reading. In N. C., abundant in the gold sand Burke, McDowell, Polk, Rutherford, Henderson, and other counties. In Col., with a phyllite, etc., in the Pike's Peak region in El Paso Co.; at Cheyenne Mt. In Cal., in au ferous gravels.

In Canada, at Grenville, Argenteuil Co.; in Templeton and adjoining townships Ottawa Co., Quebec; in Renfrew Co., sometimes very large; in North Burgess, Lanark

Use. — Zircon in its transparent varieties serves frequently as a gem stone; also a source of zirconium oxide used in the manufacture of the incandescent gas mantles.

Malacon is an altered zircon. *Cyrtolite* is related but contains uranium, yttrium and other rare elements.

Naëgite is apparently zircon with yttrium, niobium-tantalum, thorium, and uranium oxides. Occurs in spheroidal aggregates near Takoyama, Mino, Japan. Color green, gray, brown. H. = 7·5. G. = 4·1.

Thorite. Thorium silicate, $ThSiO_4$, like zircon in form; usually hydrated, black in color, and then with G. = 4·5–5; also orange-yellow and with G. = 5·19–5·40 (*orangit*). From the Brevik region and Arendal, Norway.

Auerlite. Like zircon in form; supposed to be a silico-phosphate of thorium. Henderson Co., N. C.

Danburite-Topaz Group. Orthorhombic. $\overset{\text{II}}{R}\overset{\text{III}}{R}_2(SiO_4)_2$ or $(\overset{\text{III}}{R}O)\overset{\text{III}}{R}SiO_4$

Danburite	$CaB_2(SiO_4)_2$	$a : b : c = 0·5444 : 1 : 0·4807$
Topaz	$[Al(F,OH)_2]AlSiO_4$	$a : b : c = 0·5285 : 1 : 0·4770$
Andalusite	$(AlO)AlSiO_4$	$\frac{1}{2} b : a : \frac{2}{3} c = 0·5070 : 1 : 0·4749$
		or $a : b : c = 0·9861 : 1 : 0·7025$

Sillimanite	Al_2SiO_5	Orthorhombic	$a : b = 0·970 : 1$
Cyanite	Al_2SiO_5	Triclinic	

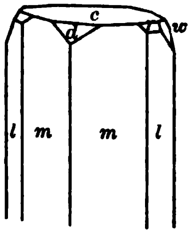
$a : b : c = 0·8994 : 1 : 0·7090$; $\alpha = 90° 5\frac{1}{2}'$, $\beta = 101° 2'$, $\gamma = 105° 44\frac{1}{2}'$.

DANBURITE.

Orthorhombic. Axes $a : b : c = 0·5444 : 1 : 0·4807$.

mm''', $110 \wedge 1\bar{1}0 = 57° 8'$. dd', $101 \wedge \bar{1}01 = 82° 53'$.
ll', $120 \wedge \bar{1}20 = 85° 8'$. ww', $041 \wedge 0\bar{4}1 = 125° 3'$.

878



Habit prismatic, resembling topaz. Also in indistinct embedded crystals, and disseminated masses.

Cleavage: *c* (001) very indistinct. Fracture uneven to subconchoidal. Brittle. H. = 7–7·25. G. = 2·97–3·02. Color pale wine-yellow to colorless, yellowish white, dark wine-yellow, yellowish brown. Luster vitreous to greasy, on crystal surfaces brilliant. Transparent to translucent. Streak white. Optically −. 2V = 88°. $\alpha = 1·632$. $\beta = 1·634$. $\gamma = 1·636$.

Comp. — $CaB_2(SiO_4)_2$ or $CaO.B_2O_3.2SiO_2$ = Silica 48·8, boron trioxide 28·4, lime 22·8 = 100.

Pyr., etc. — B.B. fuses at 3·5 to a colorless glass, and imparts a green color to the O. F. (boron). Not decomposed by hydrochloric acid, but sufficiently attacked for the solution to give the reaction of boric acid with turmeric paper. When previously ignited gelatinizes with hydrochloric acid. Phosphoresces on heating, giving a reddish light.

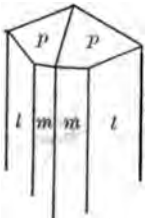
Obs. — Occurs at Danbury, Conn., with microcline and oligoclase in dolomite. At Russell, N. Y., in fine crystals. On the Piz Valatscha, the northern spur of Mt. Skopi south of Dissentis in eastern Switzerland, in slender prismatic crystals and elsewhere in Switzerland. In crystals from Takachio, Hinga, and from Obira, Bungo, Japan. From Mt. Bity and Maharitra, Madagascar.

Barsowite. This doubtful species, occurring with blue corundum in the Ural Mts., is by some authors classed with danburite; composition CaAl$_2$Si$_2$O$_8$ like anorthite.

TOPAZ.

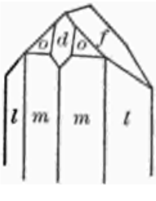
Orthorhombic. Axes $a : b : c = 0·52854 : 1 : 0·47698$.

879



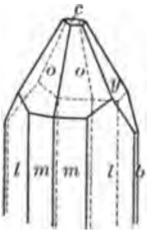
Brazil

880



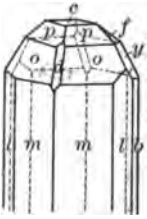
Japan

881



Durango

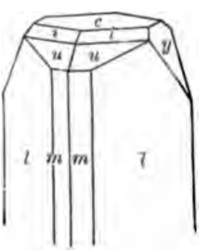
882



Ural

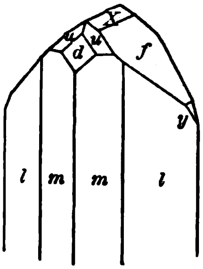
mm''', $110 \wedge 1\bar{1}0$ = 55° 43'. *yy'*, $041 \wedge 0\bar{4}1$ = 124° 41'. *uu'*, $111 \wedge \bar{1}11$ = 78° 20'.
ll, $120 \wedge \bar{1}20$ = ~~86° 49'~~: *ci*, $001 \wedge 223$ = 34° 14'. *uu'''*, $111 \wedge 1\bar{1}1$ = 39° 0'.
dd', $201 \wedge \bar{2}01$ = 122° 1'. *cu*, $001 \wedge 111$ = 45° 35'. *oo'*, $221 \wedge \bar{2}21$ = 105° 7'.
XX', $043 \wedge 0\bar{4}3$ = 64° 55'. *co*, $001 \wedge 221$ = 63° 54'. *oo'''* $221 \wedge 2\bar{2}1$ = 49° 37½'.
ff', $021 \wedge 0\bar{2}1$ = 87° 18'.

883



Ural

884



Japan

Crystals commonly prismatic, *m* (110) predominating; or *l* (120) and the form then a nearly square prism resembling andalusite. Faces in the prismatic zone often vertically striated, and often showing vicinal planes. Also firm columnar; granular, coarse or fine.

Cleavage: *c* (001) highly perfect. Fracture subconchoidal to uneven. Brittle. H. = 8. G. = 3·4–3·6. Luster vitreous. Color straw-yellow, wine-yellow, white, grayish, greenish, bluish, reddish. Streak uncolored. Transparent to subtranslucent. Optically +. Ax. pl. || *b* (010). Bx ⊥ *c* (001). Axial angles variable. 2V = 49° to 66°. Refractive indices, Brazil:

For D $\alpha = 1·62936$ $\beta = 1·63077$ $\gamma = 1·63747$ $\therefore$ 2V = 49° 31'

Var. — *Ordinary.* In prismatic crystals usually colorless or pale yellow, less often pale blue, pink, etc. The yellow of the Brazilian crystals is changed by heating to a pale rose-pink. Often contains inclusions of liquid CO$_2$.

Physalite, or *pyrophysalite*, is a coarse nearly opaque variety, from Finbo, Sweden; intumesces when heated, hence its name from φυσαλίς, *bubble*, and πῦρ, *fire*. *Pycnite* has a columnar, very compact structure. Rose made out that the cleavage was the same, and the form probably the same; and Des Cloizeaux showed that the optical characters were those of topaz.

Comp. — $(AlF)_2SiO_4$; usually containing hydroxyl and then $[Al(F,OH)]_2SiO_4$ or as given on p. 522. The former requires Silica 32·6, alumina 55·4, fluorine 20·7 = 108·7, deduct (O = 2F) 8·7 = 100.

Pyr., etc. — B.B. infusible. Fused in the closed tube, with potassium bisulphate gives the characteristic fluorine reactions. With cobalt solution the pulverized mineral gives a fine blue on heating. Only partially attacked by sulphuric acid. A variety of topaz from Brazil, when heated, assumes a pink or red hue, resembling the Balas ruby.

Diff. — Characterized by its prismatic crystals with angles of 56° (124°) or 87° (93°): also by the perfect basal cleavage; hardness; infusibility; yields fluorine B.B.

Artif. — Topaz has been made artificially by heating a mixture of silica and aluminium fluoride and then igniting this mixture in silicon fluoride gas.

Obs. — Topaz occurs especially in the highly acid igneous rocks of the granite family, as granite and rhyolite, in veins and cavities, where it appears to be the result of fumarole action after the crystallization of the magma; sometimes also in the surrounding schists, gneisses, etc., as a result of such action. In these occurrences often accompanied by fluortie, cassiterite, tourmaline. Frequently occurs in tin-bearing pegmatites. Topaz alters aesily into a compact mass of muscovite.

Fine topaz comes from Russia from the Ural Mts., from Alabashka, in the region of Ekaterinburg; from Miask in the Ilmen Mts.; also the gold-washings on the River Sanarka in Govt. Orenburg; in Nerchinsk, beyond Lake Baikal, in the Adun-Chalon Mts., etc.; in the province of Minas Geraes, Brazil, at Ouro Preto and Villa Rica, of deep yellow color; in Germany at the tin mines of Zinnwald and Ehrenfriedersdorf, and smaller crystals at Schneckenstein and Altenberg; sky-blue crystals in Cairngorm, Aberdeenshire, Scotland; the Mourne mountains, Ireland; on the island of Elba. *Physalite* occurs in crystals of great size, at Fossum, Norway; Finbo, Sweden. *Pycnite* is from the tin mine of Altenberg in Saxony; also of Schlackenwald, Zinnwald, etc. Fine crystals occur at Durango, Mexico, with tin ore; at San Luis Potosi in rhyolite. Mt. Bischoff, Tasmania, with tin ores; similarly in New South Wales. In Japan in pegmatite from Otani-yama, Province of Omi, near Kioto.

In the United States, in Me., at Stoneham, in albitic granite. In Conn., at Trumbull, with fluorite; at Willimantic. In N. C., at Crowder's Mountain. In Col., in fine crystals colorless or pale blue from the Pike's Peak region; at Nathrop, Chaffee Co., in wine-colored crystals with spessartite in lithophyses in rhyolite; similarly in the rhyolite of Chalk Mt. In Texas in fine crystals at Streeter. In Utah, in fine transparent colorless crystals with quartz and sanidine in the rhyolite of the Thomas Range, 40 miles north of Sevier Lake. In Col. in Ramona Co.

The name topaz is from τοπάζιος, an island in the Red Sea, as stated by Pliny. But the topaz of Pliny was not the true topaz, as it "yielded to the file." Topaz was included by Pliny and earlier writers, as well as by many later, under the name *chrysolite*.

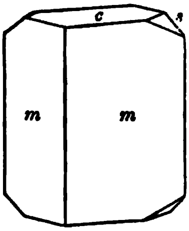
Use. — As a gem stone.

ANDALUSITE.

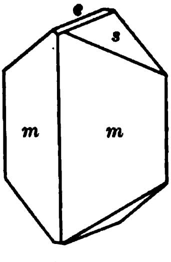
Orthorhombic. Axes $a : b : c = 0{\cdot}9861 : 1 : 0{\cdot}70245$.

mm''', 110 ∧ $1\bar{1}0$ = 89° 12'.
ss', 011 ∧ $0\bar{1}1$ = 70° 10'.

885



886

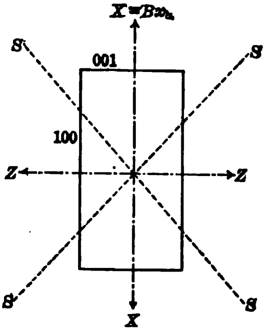


Usually in coarse prismatic forms, the prisms nearly square in form. Massive, imperfectly columnar; sometimes radiated and granular.

Cleavage: *m* (110) distinct, sometimes perfect (Brazil); *a* (100) less perfect; *b* (010) in traces. Fracture uneven, subconchoidal. Brittle. H. = 7·5. G = 3·16 –3·20. Luster vitreous; often weak. Color whitish, rose-red, flesh-red, violet, pearl-gray, reddish brown, olive-green.

Streak uncolored. Transparent to opaque, usually subtranslucent. Pleochroism strong in some colored varieties. Absorption strong, $X > Y > Z$. Sections normal to an optic axis are idiophanous or show the polarization-brushes distinctly (p. 288). Optically −. Ax. pl. $\|$ *b* (010). Bx $\perp$ *c* (001). 2V = 85°. $\alpha = 1{\cdot}632$. $\beta = 1{\cdot}638$. $\gamma = 1{\cdot}643$.

887



Var. — *Chiastolite*, or *Macle* is a variety in stout crystals having the axis and angles of a different color from the rest, owing to a regular arrangement of carbonaceous impurities through the interior, and hence exhibiting a colored cross, or a tesselated appearance in a transverse section. Fig. 888 shows sections of a crystal. *Viridine* is a green variety containing some iron and manganese from near Darmstadt, Germany.

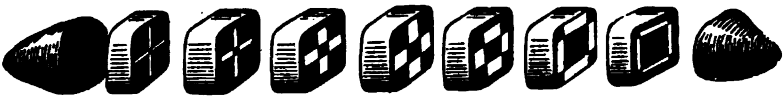
Comp. — $Al_2SiO_5 = (AlO)AlSiO_4$ or $Al_2O_3.SiO_2$ = Silica 36·8, alumina 63·2 = 100. Manganese is sometimes present, as in *manganandalusite*.

Pyr., etc. — B.B. infusible. With cobalt solution gives a blue color after ignition. Not decomposed by acids. Decomposed on fusion with caustic alkalies and alkaline carbonates.

Diff. — Characterized by the nearly square prism, pleochroism, hardness, infusibility; reaction for alumina B.B.

Micro. — Distinguished in thin sections by its high relief; low interference-colors, which are only slightly above those of quartz; negative biaxial character; negative extension of the crystals (diff. from sillimanite); rather distinct prismatic cleavage and the constant parallel extinction (diff. from pyroxenes, which have also greater birefringence); also by its characteristic arrangement of impurities when these are present (Fig. 888). The pleochroism, which is often lacking, is, when present, strong and characteristic.

888



Obs. — Most common in argillaceous schist, or other schists imperfectly crystalline; also in gneiss, mica schist and related rocks; rarely in connection with serpentine. The variety chiastolite is commonly a contact mineral in clay-slates, *e.g.*, adjoining granitic dikes. Sometimes associated with sillimanite with parallel axes.

Found in Spain, in Andalusia; in Austria in the Tyrol, Lisens Alp; in Saxony, at Bräunsdorf; Bavaria, at Wunsiedel, etc. In Brazil, province of Minas Geraes, in fine crystals and as rolled pebbles. Remarkable crystals of chiastolite from Mt. Howden, near Bimbowrie, South Australia.

In North America, in Me., at Standish. N. H., White Mtn. Notch; Mass., at Westford; Lancaster, both varieties; Sterling, chiastolite. Conn., at Litchfield and Washington. Pa., in Delaware Co., near Leiperville, large crystals; Upper Providence.

Named from Andalusia, the first locality noted. The name *macle* is from the Latin *macula*, a spot. Chiastolite is from χιάστος, *arranged diagonally*, and hence from *chi*, the Greek name for the letter X.

Use. — When clear and transparent may serve as a gem stone.

Guarinite. $2(K,Na)_2O.8CaO.5(Al,Fe,Ce)_2O_3.10SiO_2$. Orthorhombic. In minute thin tables, flattened $\|$ *b* (010), nearly tetragonal in form. H. = 6·5. G. = 2·9–3·3. Color sulphur-yellow, honey-yellow. Pleochroic, canary-yellow to colorless. Found in a grayish trachyte on Mte. Somma, Vesuvius. Axial ratio and optical properties agree closely with those of danburite.

SILLIMANITE. Fibrolite.

Orthorhombic. Axes $a : b = 0{\cdot}970 : 1$. *mm'''* 110 ∧ 110 = 88° 15′, *hh'* 230 ∧ $\bar{2}30$ = 69°. Prismatic faces striated and rounded. Commonly in long slender crystals not distinctly terminated; often in close parallel groups, passing into fibrous and columnar massive forms; sometimes radiating.

Cleavage: *b* (010) very perfect. Fracture uneven. H. = 6–7. G. = 3·23–3·24. Luster vitreous, approaching subadamantine. Color hair-brown, grayish brown, grayish white, grayish green, pale olive-green. Streak uncolored. Transparent to translucent. Pleochroism sometimes distinct. Optically +. Double refraction strong. Ax. pl. || *b* (010). Bx ⊥ *c* (001). Dispersion $\rho > \upsilon$. Axial angle and indices variable. 2V = 20° (approx.). $\alpha = 1{\cdot}638$. $\beta = 1{\cdot}642$. $\gamma = 1{\cdot}653$.

Comp. — $Al_2SiO_5 = (AlO)AlSiO_4$, like andalusite. Silica 36·8, alumina 63·2 = 100.

Sillimanite is the most stable of the three aluminium silicates. Both andalusite and cyanite are converted into sillimanite when strongly heated.

Pyr. — Same as andalusite.

Diff. — Characterized by its fibrous or columnar form; perfect cleavage; infusibility; reaction for alumina.

Micro. — In thin sections recognized by its form, usually with transverse fractures; parallel extinction; high interference-colors.

Artif. — Sillimanite has been made artificially by fusing its oxides together. Both andalusite and cyanite are converted into sillimanite when strongly heated.

Obs. — Often present in the quartz of gneisses and sometimes granites in very slender, minute prisms commonly aggregated together and sometimes intergrown with andalusite; iolite is also a common associate; rarely as a contact mineral; often occurs with corundum.

Observed in many localities, thus near Moldau in Bohemia; at Fassa in Tyrol, Austria (*bucholzite*); in the Carnatic, India, with corundum (*fibrolite*); at Bodenmais, Bavaria; Freiberg, Saxony; in France, near Pontgibaud and other points in Auvergne; forms rolled masses in the diamantiferous sands of Minas Geraes, Brazil.

In the United States, in Mass., at Worcester. In Conn.; near Norwich, with zircon, monazite and corundum; at Willimantic. In N. Y., at Yorktown, Westchester Co.; in Monroe, Orange Co., (*monrolite*). In Pa., at Chester on the Delaware, near Queensbury forge; in Delaware Co.; Del., at Brandywine Springs. With corundum in N. C.

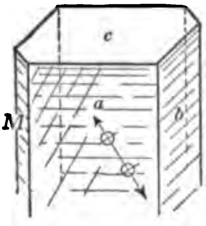
Named *fibrolite* from the fibrous massive variety; *sillimanite*, after Prof. Benjamin Silliman of New Haven (1779–1864).

Bamlite, *xenolite*, *wörthite* probably belong to sillimanite; the last is altered.

CYANITE. Kyanite. Disthene.

Triclinic. Axes $a : b : c = 0{\cdot}8994 : 1 : 0{\cdot}7090$; $\alpha = 90°\ 5\tfrac{1}{2}'$, $\beta = 101°\ 2'$, $\gamma = 105°\ 44\tfrac{1}{2}'$. *ac*, 100 ∧ 001 = 78° 30′; *bc*, 010 ∧ 001 = 86° 45′.

889



Usually in long bladed crystals, rarely terminated. Also coarsely bladed columnar to subfibrous.

Cleavage: *a* (100) very perfect; *b* (010) less perfect; also parting || *c* (001). H. = 5–7·25; the least, 4–5, on *a* (100) || *c* axis; 6–7 on *a* (100) || edge *a* (100)/ *c* (001); 7 on *b* (010). G. = 3·56–3·67. Luster vitreous to pearly. Color blue, white; blue along the center of the blades or crystals with white margins; also gray, green, black. Streak uncolored. Translucent to transparent. Pleochroism distinct in colored varieties. Optically –. Ax. pl. nearly ⊥ *a* (100) and inclined to edge *a*/*b* on *a* about 30°, and about 7½° on *b* (010), cf. Fig. 889. 2V = 82°. $\alpha = 1{\cdot}717$. $\beta = 1{\cdot}722$. $\gamma = 1{\cdot}729$.

Comp. — Empirical formula Al_2SiO_5 or $Al_2O_3.SiO_2$, like andalusite and sillimanite. Perhaps a basic metasilicate, $(AlO)_2SiO_3$.

Pyr., etc. Same as for andalusite. At a high temperature cyanite assumes the physical characters of sillimanite.

Diff. — Characterized by the bladed form; common blue color; varying hardness; infusibility; reaction for alumina.

Obs. — Occurs principally in gneiss and mica schist (both the ordinary variety with muscovite and also that with paragonite) often accompanied by garnet and sometimes by staurolite; also in eclogite schist. It is often associated with corundum.

Found in transparent crystals at Monte Campione in the St. Gothard region in Switzerland in paragonite schist; on Mt. Greiner, Zillertal, and in the Pfitschtal (*rhætizite*, white) in Tyrol, Austria; in eclogite of the Saualpe, Carinthia; Horrsjöberg in Wermland, Sweden; Villa Rica, Brazil, etc.

In Mass., at Chesterfield, with garnet in mica schist. In Conn., at Litchfield, Washington, Canton, Barkhamstead, etc. In Ver., at Thetford. In Pa., in Chester Co. and in Delaware Co. In Va., Buckingham Co. In N. C., with rutile, lazulite, etc., at Crowder's Mt., Gaston Co.; in Gaston and Rutherford counties associated with corundum, damourite; beautiful clear green in Yancey Co. Named from *κυανός, blue.*

Datolite Group. Monoclinic

Basic Orthosilicates. $H\overset{II}{R}\overset{III}{R}SiO_5$ or $\overset{II}{R}_3\overset{III}{R}_2(SiO_5)_2$. Oxygen ratio for R : Si = 3 : 2.

$\overset{II}{R}$ = Ca,Be,Fe, chiefly; $\overset{III}{R}$ = Boron, the yttrium (and cerium) metals, etc.

	$a : b : c$	β
Datolite	0·6345 : 1 : 1·2657	89° 51′
$HCaBSiO_5$ or $Ca(BOH)SiO_4$		
Homilite	0·6249 : 1 : 1·2824	89° 21′
$Ca_2FeB_2Si_2O_{10}$ or $Ca_2Fe(BO)_2(SiO_4)_2$		
	$2a : b : 4c$	β
Euclase	0·6474 : 1 : 1·3330	79° 44′
$HBeAlSiO_5$ or $Be(AlOH)SiO_4$	a	
Gadolinite	0·6273 : 1 : 1·3215	89° 26½′
$Be_2FeY_2Si_2O_{10}$ or $Be_2Fe(YO)_2(SiO_4)_2$		

The species of the DATOLITE GROUP are usually regarded as basic orthosilicates, the formulas being taken in the second form given above. They all crystallize in the monoclinic system, and all but Euclase conform closely in axial ratio; with the latter there is also a distinct morphological relationship.

DATOLITE.

Monoclinic. Axes $a : b : c$ = 0·6345 : 1 : 1·2657; β = 89° 51⅓′.

mm‴,	$110 \wedge 1\bar{1}0$ =	64° 47′.	*cn*,	$001 \wedge 111$ =	66° 57′.
ac,	$100 \wedge 001$ =	89° 51′.	*cm*,	$001 \wedge 110$ =	89° 53′.
ax,	$100 \wedge 101$ =	45° 0′.	*cε*,	$001 \wedge \bar{1}12$ =	49° 49′.
gg′,	$012 \wedge 0\bar{1}2$ =	64° 39½′.	*nn′*,	$111 \wedge 1\bar{1}1$ =	59° 4½′.
$m_x m_x'$,	$011 \wedge 0\bar{1}1$ =	103° 23′.	*εε′*,	$\bar{1}12 \wedge \bar{1}\bar{1}2$ =	48° 19½′.

Crystals varied in habit; usually short prismatic with either *m* (110) or m_x (011) predominating; sometimes tabular || *x* (201); also of other types, and often highly modified (Figs. 890–893). Also botryoidal and globular, having a columnar structure; divergent and radiating; sometimes massive, granular to compact and crypto-crystalline.

Cleavage not observed. Fracture conchoidal to uneven. Brittle.

The **Epidote Group** includes the above complex orthosilicates. The monoclinic species agree closely in form. To them the orthorhombic species zoisite is also related in angle, its prismatic zone corresponding to the monoclinic orthodomes, etc. Thus we have:

Zoisite	*mm'''*, $110 \wedge 1\bar{1}0 = 63° 34'$.	Epidote	*cr*, $001 \wedge \bar{1}01 = 63° 42'$.
	uu', $021 \wedge 0\bar{2}1 = 68° 54'$.		*mm'*, $110 \wedge \bar{1}10 = 70° 4'$, etc.

There seems to be, however, a monoclinic calcium compound, having the composition of zoisite, but monoclinic and strictly isomorphous with ordinary epidote; it is called *clinozoisite*.

ZOISITE.

Orthorhombic. Axes $a : b : c = 0{\cdot}6196 : 1 : 0{\cdot}34295$.

mm''', $110 \wedge 1\bar{1}0 = 63° 34'$.	*ff'*, $011 \wedge 0\bar{1}1 = 37° 52'$.
dd', $101 \wedge \bar{1}01 = 57° 56'$.	*oo'''*, $111 \wedge 1\bar{1}1 = 33° 24'$.

Crystals prismatic, deeply striated or furrowed vertically, and seldom distinctly terminated. Also massive; columnar to compact.

Cleavage: *b* (010) very perfect. Fracture uneven to subconchoidal. Brittle. H. = 6–6·5. G. = 3·25–3·37. Luster vitreous; on the cleavage-face, *b* (010), pearly. Color grayish white, gray, yellowish brown, greenish gray, apple-green; also peach-blossom-red to rose-red. Streak uncolored. Transparent to subtranslucent.

Pleochroism strong in pink varieties. Optically +. Ax. pl. usually $\parallel b$ (010); also $\parallel c$ (001). Bx $\perp a$ (100). Dispersion strong, $\rho < v$; also $\rho > v$. Axial angle variable even in the same crystal. 2V = 0°–60°. $\alpha = 1{\cdot}700$. $\beta = 1{\cdot}703$. $\gamma = 1{\cdot}706$.

Var. — 1. *Ordinary.* Colors gray to white and brown; also green. Usually in indistinct prismatic or columnar forms; also in fibrous aggregates. G. = 3·226–3·381. *Unionite* is a very pure zoisite. 2. *Rose-red* or *Thulite.* Fragile; pleochroism strong. 3. *Compact, massive.* Includes the essential part of most of the mineral material known as *saussurite* (*e.g.*, in saussurite-gabbro), which has arisen from the alteration of feldspar.

Comp. — $HCa_2Al_3Si_3O_{13}$ or $4CaO.3Al_2O_3.6SiO_2.H_2O$ = Silica 39·7, alumina 33·7, lime 24·6, water 2·0 = 100. The alumina is sometimes replaced by iron, thus graduating toward epidote, which has the same general formula.

Pyr., etc. — B.B. swells up and fuses at 3–3·5 to a white blebby mass. Not decomposed by acids; when previously ignited gelatinizes with hydrochloric acid. Gives off water when strongly ignited.

Diff. — Characterized by the columnar structure; fusibility with intumescence; resembles some amphibole.

Micro. — Distinguished in thin sections by its high relief and very low interference-colors; lack of color and biaxial character. From epidote it is distinguished by its lack of color and low birefringence; from vesuvianite by its color and biaxial character. Thin sections frequently show the "*ultra blue*" (p. 520) between crossed nicols.

Obs. — Occurs especially in those crystalline schists which have been formed by the dynamic metamorphism of basic igneous rocks containing plagioclase rich in lime. Commonly accompanies some one of the amphiboles (actinolite, smaragdite, glaucophane, etc.); thus in amphibolite, glaucophane schist, eclogite; often associated with corundum.

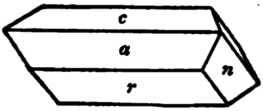
The original zoisite is that of the eclogite of the Saualpe in Carinthia (*saualpite*). Other localities are: Rauris in Salzburg; Sterzing, etc., in Tyrol, Austria; the Fichtelgebirge in Bavaria; Marschendorf in Moravia; Saastal in Switzerland; the island of Syra, one of the Cyclades, in glaucophane schist. In crystals from Chester, Mass.. *Thulite* occurs at Kleppan in Tellemarken, Norway, and at Traversella in Piedmont, Italy.

EPIDOTE. Pistacite.

Monoclinic. Axes $a : b : c = 1·5787 : 1 : 1·8036$; $\beta = 64° 37'$.

mm''', $110 \wedge 1\bar{1}0 = 109° 56'$.
ca, $001 \wedge 100 = 64° 37'$.
ce, $001 \wedge 101 = 34° 43'$.
cr, $001 \wedge \bar{1}01 = 63° 42'$.
ar', $100 \wedge 10\bar{1} = 51° 41'$.
cl, $001 \wedge \bar{2}01 = 89° 26'$.
co, $001 \wedge 011 = 58° 28'$.
cn, $001 \wedge \bar{1}11 = 75° 11'$.
an''', $100 \wedge 11\bar{1} = 69° 2'$.
nn''', $\bar{1}11 \wedge 11\bar{1} = 70° 29'$.

894



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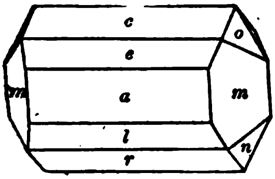

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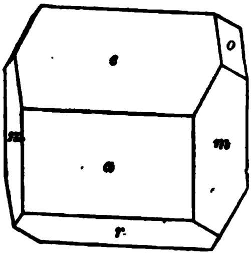

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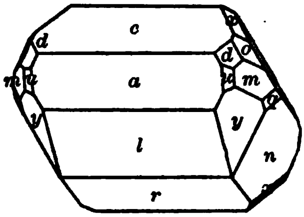
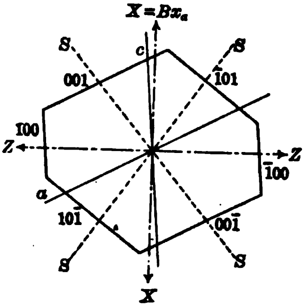


Twins: tw. pl. *a* (100) common, often as embedded tw. lamellæ. Crystals usually prismatic || the ortho-axis *b* and terminated at one extremity only; passing into acicular forms; the faces in the zone *a* (100)/*c* (001) deeply striated. Also fibrous, divergent or parallel; granular, particles of various sizes, sometimes fine granular, and forming rock-masses.

Cleavage: *c* (001) perfect; *a* (100) imperfect. Fracture uneven. Brittle. H. = 6–7. G. = 3·25–3·5. Luster vitreous; on *c* (001) inclining to pearly or resinous. Color pistachio-green or yellowish green to brownish green, greenish black, and black; sometimes clear red and yellow; also gray and grayish white, rarely colorless. Streak uncolored, grayish. Transparent to opaque: generally subtranslucent.

Pleochroism strong: vibrations || Z green, Y brown and strongly absorbed, X yellow. Absorption usually $Y > Z > X$; but sometimes $Z > Y > X$ in the variety of epidote common in rocks. Often exhibits idiophanous figures; best in sections normal to an optic axis, but often to be observed in natural crystals (Sulzbach), especially if flattened || *r* ($\bar{1}01$). (See p. 288.) Optically −. Ax. pl. || *b* (010). $Bx_{a.r} \wedge c$ axis = − 2° 56′. Hence $Z \perp a$ (100) nearly. Dispersion inclined, strongly marked; of the axes feeble, $\rho > v$. Axial angle large. $\alpha = 1·729$. $\beta = 1·754$. $\gamma = 1·768$.

898



Var. — Epidote has ordinarily a peculiar yellowish green (pistachio) color, seldom found in other minerals. But this color passes into dark and light shades — black on one side and brown on the other; red, yellow and colorless varieties also occur.

Var. 1. *Ordinary.* Color green of some shade, as described, the pistachio tint rarely absent. (*a*) In crystals. (*b*) Fibrous. (*c*) Granular massive. (*d*) *Scorza* is epidote sand from the gold washings in Transylvania. The Arendal, Norway, epidote (*Arendalite*) is mostly in dark green crystals; that of Bourg d'Oisans, Dauphiné, France, (*Thallite, Del-*

phinite, Oisanite) in yellowish green crystals, sometimes transparent. *Puschkinite* includes crystals from the auriferous sands of Ekaterinburg, Ural Mts. *Achmatite* is ordinary epidote from Achmatovsk, Ural Mts. A variety from Garda, Hoste Island, Terra del Fuego, is colorless and resembles zoisite.

2. The *Bucklandite* from Achmatovsk, Ural Mts., described by Hermann, is black with a tinge of green, and differs from ordinary epidote in having the crystals nearly symmetrical and not, like other epidote, lengthened in the direction of the ortho-axis. G. = 3·51.

3. *Withamite*. Carmine-red to straw-yellow, strongly pleochroic; deep crimson and straw-yellow. H. = 6–6·5; G. = 3·137; in small radiated groups. From Glencoe, in Argyleshire, Scotland. Sometimes referred to piedmontite, but contains little MnO.

4. *Tawmanite* is a chromium-bearing epidote from Tawman, Kachin Hills, Upper Burma. Deep green color and strong pleochroism, emerald-green to bright yellow.

Comp. — $HCa_2(Al,Fe)_3Si_3O_{13}$ or $H_2O.4CaO.3(Al,Fe_3)_2O_3.6SiO_2$, the ratio of aluminium to iron varies commonly from 6 : 1 to 3 : 2. Percentage composition:

For Al : Fe = 3 : 1 SiO_2 37·87, Al_2O_3 24·13, Fe_2O_3 12·60, CaO 23·51, H_2O 1·89 = 100

Clinozoisite is an epidote without iron, having the composition of zoisite; *fouqueite* is probably the same from an anorthite-gneiss in Ceylon. *Picroepidote* is supposed to contain Mg in place of Ca.

Pyr., etc. — In the closed tube gives water on strong ignition. B.B. fuses with intumescence at 3–3·5 to a dark brown or black mass which is generally magnetic. Reacts for iron and sometimes for manganese with the fluxes. Partially decomposed by hydrochloric acid, but when previously ignited, gelatinizes with acid. Decomposed on fusion with alkaline carbonates.

Diff. — Characterized often by its peculiar yellowish green (pistachio) color; readily fusible and yields a magnetic globule B.B. Prismatic forms often longitudinally striated, but they have not the angle, cleavage or brittleness of tremolite; tourmaline has no distinct cleavage, is less fusible (in common forms) and usually shows its hexagonal form.

Micro. — Recognized in thin sections by its high refraction; strong interference-colors rising into those of the third order in ordinary sections; decided color and striking pleochroism; also by the fact that the plane of the optic axes lies transversely to the elongation of the crystals.

Obs. — Epidote is commonly formed by the metamorphism (both local igneous and of general dynamic character) of impure calcareous sedimentary rocks or igneous rocks containing much lime. It thus often occurs in gneissic rocks, mica schist, amphibole schist, serpentine; so also in quartzites, sandstones and limestones altered by neighboring igneous rocks. Often accompanies beds of magnetite or hematite in such rocks. Has also been found in granite (Maryland), and regarded as an original mineral.

It is often associated with quartz, feldspar, actinolite, axinite, chlorite, etc. It sometimes forms with quartz an epidote rock, called *epidosite*. A similar rock exists at Melbourne in Canada. A gneissoid rock consisting of flesh-colored orthoclase, quartz and epidote from the Unaka Mts. (N. C. and Tenn.) has been called unakyte.

Beautiful crystallizations come from Bourg d'Oisans, Dauphiné, France; the Ala valley and Traversella, in Piedmont, Italy; Elba; Zermatt, Switzerland; Zillertal in Tyrol, Austria; also in fine crystals from the Knappenwand in the Untersulzbachtal, Pinzgau, Austria, associated with asbestus, adularia, apatite, titanite, scheelite; further at Striegau, Silesia; Zöptau, Moravia; Arendal, Norway; the Achmatovsk mine near Zlatoust, Ural Mts.

In North America, occurs in N. H., at Franconia and Warren. In Mass., at Hadlyme and Chester in crystals in gneiss; at Athol, in syenitic gneiss, in fine crystals; Newbury, in limestone. In Conn., at Haddam, in large splendid crystals. In N. Y., near Amity; Monroe, Orange Co.; Warwick, pale yellowish green, with titanite and pyroxene. In N. C., at Hampton's, Yancey Co.; White's mill, Gaston Co.; Franklin, Macon Co.; in crystals and crystalline masses in quartz at White Plains, Alexander Co. In Mich., in the Lake Superior region, at many of the mines. Crystals from Seven Devils mining district, Idaho; from Riverside, Cal.; from Sulzer, Prince of Wales Island, Alaska.

Epidote was named by Haüy, from the Greek *ἐπίδοσις*, *increase*, translated by him, "qui à recu un accroissement," the base of the prism (rhomboidal prism) having one side longer than the other. *Pistacite*, from *πιστακιᾳ*, *the pistachio-nut*, refers to the color.

Piedmontite. Similar in angle to ordinary epidote, but contains 5 to 15 p. c. Mn_2O_3. H. = 6·5. G. = 3·404. Color reddish brown and reddish black. Pleochroism strong.

Absorption $X > Y > Z$. Optically +. Ax. pl. ∥ b (010). $Bx_{a.r} \wedge c$ axis = + 82° 34′, $X \wedge c$ axis = − 6° to − 3°. $\beta = 1{\cdot}73$. Occurs with manganese ores at St. Marcel, Piedmont, Italy. In crystalline schists on Ile de Groix, France; in glaucophane-schist in Japan. Occasionally in quartz porphyry, as in the antique red porphyry of Egypt, also that of South Mountain, Pa.

Hancockite. Belongs in Epidote Group containing, PbO, MnO, CaO, SrO, MgO, Al_2O_3, Fe_2O_3, Mn_2O_3. Crystals which are very small and lath shaped show characteristic epidote habit and closely related angles. Brownish red. H. = 6–7. G. = 4·0. Found at Franklin, N. J.

ALLANITE. Orthite.

Monoclinic. Axes, p. 529. In angle near epidote. Crystals often tabular ∥ a (100); also long and slender to acicular prismatic by elongation ∥ axis b. Also massive and in embedded grains.

Cleavage: a (100) and c (001) in traces; also m (110) sometimes observed. Fracture uneven or subconchoidal. Brittle. H. = 5·5–6. G. = 3·0–4·2. Luster submetallic, pitchy or resinous. Color brown to black. Subtranslucent to opaque. Pleochroism strong: Z brownish yellow, Y reddish brown, X greenish brown. Optically −. Ax. pl. ∥ b (010). $Bx_a \wedge c$ axis = $32\frac{1}{2}$° approx. $\beta = 1{\cdot}682$. Birefringence variable. Also isotropic and amorphous by alteration analogous to gadolinite.

Var. — *Allanite.* The original mineral was from East Greenland, in tabular crystals or plates. Color black or brownish black. G. = 3·50–3·95. *Bucklandite* is anhydrous allanite in small black crystals from a magnetite mine near Arendal, Norway. *Bagrationite* occurs in black crystals which are like the bucklandite of Achmatovsk (epidote).

Orthite included, in its original use, the slender or acicular prismatic crystals, containing some water, from Finbo, near Falun, Sweden. But these graduate into massive forms, and some orthites are anhydrous, or as nearly so as most allanite. The name is from *ὀρθός straight.*

Comp. — Like epidote $H\overset{II}{R}\overset{III}{R}_3Si_3O_{13}$ or $H_2O.4RO.3R_2O_3.6SiO_2$ with $\overset{II}{R}$ = Ca and Fe, and $\overset{III}{R}$ = Al,Fe, the cerium metals Ce, Di, La, and in smaller amounts those of the yttrium group. Some varieties contain considerable water, but probably by alteration.

Pyr., etc. — Some varieties give much water in the closed tube, and all kinds yield a small amount on strong ignition. B.B. fuses easily and swells up (F. = 2·5) to a dark, blebby, magnetic glass. With the fluxes reacts for iron. Most varieties gelatinize with hydrochloric acid, but if previously ignited are not decomposed by acid.

Obs. — Occurs in albitic and common feldspathic granite, gneiss, syenite, zircon syenite, porphyry. Thus in Greenland; Norway; Sweden; Striegau, Silesia. Also in white limestone as at Auerbach on the Bergstrasse, Germany; often in mines of magnetic iron. Rather common as an accessory constituent in many rocks, as in andesite, diorite, dacite, rhyolite, the tonalite of Mt. Adamello, Austria, the scapolite rocks of Odegaarden, Norway, etc. Sometimes inclosed as a nucleus in crystals of the isomorphous species, epidote. From Madagascar.

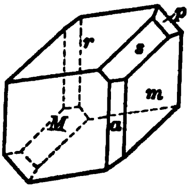
At Vesuvius in ejected masses with sanidine, sodalite, nephelite, hornblende, etc. Similarly in trachytic ejected masses at the Laacher See, Germany (*bucklandite*).

In Mass., at the Bolton quarry. In N. Y., Moriah, Essex Co., with magnetite and apatite; at Monroe, Orange Co. In N. J., at Franklin Furnace with feldspar and magnetite. In Pa., at South Mountain, near Bethlehem, in large crystals; at East Bradford; near Eckhardt's furnace, Berks Co., abundant. In Va., in large masses in Amherst Co.; also in Bedford, Nelson, and Amelia counties. In N. C., at many points. At the Devil's Head Mt., Douglas Co., Col. In Texas in Llano Co.

AXINITE.

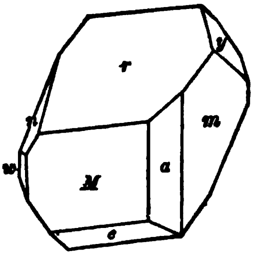
Triclinic. Axes $a : b : c = 0{\cdot}4921 : 1 : 0{\cdot}4797$; $\alpha = 82° 54'$, $\beta = 91° 52'$, $\gamma = 131° 32'$.

899



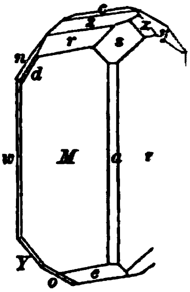
Dauphiné

900



Poloma

901



Bethlehem, P

am, $100 \wedge 110 = 15° 34'$.
aM, $100 \wedge 1\bar{1}0 = 28° 55'$.
as, $100 \wedge 201 = 21° 37'$.
Mr, $1\bar{1}0 \wedge 1\bar{1}1 = 45° 15'$.
mr, $110 \wedge 1\bar{1}1 = 64° 22'$.
ms, $110 \wedge 201 = 27° 57'$.

Crystals usually broad and acute-edged, but varied in habit. Also m sive, lamellar, lamellæ often curved; sometimes granular.

Cleavage: *b* (010) distinct. Fracture conchoidal. Brittle. H. = 6·5 G. = 3·271–3·294. Luster highly glassy. Color clove-brown, plum-b and pearl-gray; also honey-yellow, greenish yellow. Streak uncolor Transparent to subtranslucent. Pleochroism strong. Optically —. Ax. and Bx_a approximately ⊥ *x* (111). Axial angles variable. 2V = 65°–7 $\beta = 1{\cdot}68$ (approx.). Pyroelectric (p. 307).

Comp. — A boro-silicate of aluminium and calcium with varying amounts of iron and manganese. Formula, $\overset{II}{R}_7\overset{III}{R}_4B_2(SiO_4)_8$. R = Calcium chiefly, sometimes in large excess, again in smaller amount and manganese prominent; iron is present in small quantity, also magnesium and basic hydrogen.

Pyr., etc. — B.B. fuses readily with intumescence, imparts a pale green color to the O.F., and fuses at 2 to a dark green to black glass; with borax in O.F. gives an amethystine bead (manganese), which in R.F. becomes yellow (iron). Fused with a mixture of bisulphate of potash and fluorite on the platinum loop colors the flame green (boric acid). Not decomposed by acids, but when previously ignited, gelatinizes with hydrochloric acid.

Obs. — Axinite occurs in clove-brown crystals; near Bourg d'Oisans in Dauphiné, France; at Andreasberg, Harz Mts., Germany; Striegau, Silesia; on Mt. Skopi, in eastern Switzerland; Elba; at the silver mines of Kongsberg, Norway; Nordmark, Sweden; near Miask in the Ural Mts.; in Cornwall, England, of a dark color, at the Botallack mine near St. Just, etc. From Obira, Japan.

In the United States, at Phippsburg, Me.; Franklin Furnace, N. J., honey-yellow; at Bethlehem, Pa.; in Cal. at Bonsall, San Diego Co., at Riverside, Riverside Co., and at Consumers Mine, Amador Co.

Named from ἀξίνη, *an axe*, in allusion to the form of the crystals.

PREHNITE.

Orthorhombic-hemimorphic. Axes $a : b : c = 0{\cdot}8401 : 1 : 0{\cdot}5549$.

Distinct individual crystals rare; usually tabular ‖ *c* (001); sometimes prismatic, mm''' (110) ∧ (1$\bar{1}$0) = 80° 4′; again acute pyramidal. Commonly in groups of tabular crystals, united by *c* (001) making broken forms, often barrel-shaped. Reniform, globular, and stalactitic with a crystalline surface. Structure imperfectly columnar or lamellar, strongly coherent; also compact granular or impalpable.

Cleavage: *c* (001) distinct. Fracture uneven. Brittle. H. = 6–6·5. G. = 2·80–2·95. Luster vitreous; on base weak pearly. Color light green, oil-green, passing into white and gray; often fading on exposure. Subtransparent to translucent. Streak uncolored.

Comp. — An acid orthosilicate, $H_2Ca_2Al_2(SiO_4)_3$ = Silica 43·7, alumina 24·8, lime 27·1, water 4·4 = 100.

Prehnite is sometimes classed with the zeolites, with which it is often associated; the water here, however, has been shown to go off only at a red heat, and hence plays a different part.

Pyr., etc. — In the closed tube yields water. B.B. fuses at 2 with intumescence to a blebby enamel-like glass. Decomposed slowly by hydrochloric acid without gelatinizing; after fusion dissolves readily with gelatinization.

Diff. — B.B. fuses readily, unlike beryl, green quartz, and chalcedony. Its hardness is greater than that of the zeolites.

Obs. — Occurs chiefly in basic eruptive rocks, basalt, diabase, etc., as a secondary mineral in veins and cavities, often associated with some of the zeolites, also datolite, pectolite, calcite, but commonly one of the first formed of the series; also less often in granite, gneiss, syenite, and then frequently associated with epidote; sometimes associated with native copper, as in the Lake Superior region.

At St. Christophe, near Bourg d'Oisans in Dauphiné, France; Fassatal, Tyrol, Austria; the Ala valley in Piedmont, Italy; in the Harz Mts. near Andreasberg, Germany; in granite at Striegau, Silesia; Arendal, Norway; Ædelfors in Sweden (*edelite*); at Corstorphine Hill, near Edinburgh, Scotland; Mourne Mts., Ireland.

In the United States, finely crystallized at Farmington, Conn.; Paterson and Bergen Hill, N. J.; in syenite, at Somerville, Mass.; on north shore of Lake Superior, and the copper region.

Named (1790) after Col. Prehn, who brought the mineral from the Cape of Good Hope.

Harstigite. An acid orthosilicate of manganese and calcium. In small colorless prismatic crystals. H. = 5·5. G. = 3·049. Indices, 1·678–1·683. From the Harstig mine, near Pajsberg, Wermland, Sweden.

Cuspidine. Contains silica, lime, fluorine, and from alteration carbon dioxide; formula perhaps $Ca_2Si(O,F_2)_4$. In minute spear-shaped crystals. H. = 5–6. G. = 2·853–2·860. Color pale rose-red. Indices, 1·590–1·602. From Vesuvius, in ejected masses in the tufa of Monte Somma. From Franklin, N. J.

IV. Subsilicates

The species here included are basic salts, for the most part to be referred either to the metasilicates or orthosilicates, like many basic compounds already included in the preceding pages. Until their constitution is definitely settled, however, they are more conveniently grouped by themselves as SUBSILICATES. It may be noted that those species having an oxygen ratio of silicon to bases of 2 : 3, like topaz, andalusite, sillimanite, datolite, etc., also calamine, carpholite, and perhaps tourmaline, are sometimes regarded as salts of the hypothetical parasilicic acid, H_6SiO_5.

The only prominent group in this subdivision is the HUMITE GROUP.

Humite Group

			$a : b : c$	β
Prolectite	$[Mg(F,OH)]_2Mg[SiO_4]_1$?	Monoclinic	1·0803 : 1 : 1·8861	90
Chondrodite	$[Mg(F,OH)]_2Mg_3[SiO_4]_2$	Monoclinic	1·0863 : 1 : 3·1447	90
			$b : a : c$	
Humite	$[Mg(F,OH)]_2Mg_5[SiO_4]_3$	Orthorhombic	1·0802 : 1 : 4·4033	
Clinohumite	$[Mg(F,OH)]_2Mg_7[SiO_4]_4$	Monoclinic	1·0803 : 1 : 5·6588	

The species here included form a remarkable series both as regards c talline form and chemical composition. In crystallization they have sens the same ratio for the lateral axes, while the vertical axes are almost exa in the ratio of the numbers 3 : 5 : 7 : 9 (see also below). Furtherm though one species is orthorhombic, the others monoclinic, they here correspond closely, since the axial angle β in the latter cases does not sem differ from 90°.

In composition, as shown by Penfield and Howe (also Sjögren), the three species are basic orthosilicates in each of which the univalent g (MgF) or (MgOH) enters, while the Mg atoms present are in the rat 3 : 5 : 7. The composition given for Prolectite is theoretical only, b that which would be expected from its crystallization. In phy characters these species are very similar, and several of them may c together at the same locality and even intercrystallized in pa lamellæ.

The species of the group approximate closely in angle to chrysolite and chryso The axial ratios may be compared as follows:

Prolectite	$a : b : \frac{1}{3}c$	= 1·0803 : 1 : 0·6287
Chondrodite	$a : b : \frac{1}{5}c$	= 1·0863 : 1 : 0·6289
Humite	$b : a : \frac{1}{7}c$	= 1·0802 : 1 : 0·6291
Clinohumite	$a : b : \frac{1}{9}c$	= 1·0803 : 1 : 0·6288
Chrysolite	$b : 2a : c$	= 1·0735 : 1 : 0·6296
Chrysoberyl	$b : 2a : c$	= 1·0637 : 1 : 0·6170

CHONDRODITE — HUMITE — CLINOHUMITE.

Axial ratios as given above. Habit varied, Figs. 902 to 910. Twins common, the twinning planes inclined 60°, also 30°, to *c* (001) in the brachydome or clinodome zone, hence the axes crossing at angles near 60°; often repeated as trillings and as polysynthetic lamellæ (cf. Fig. 609, p. 299). Also twins, with *c* (001) as tw. plane. Two of the three species are often twinned together.

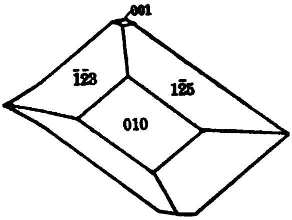
Cleavage: *c* (001) sometimes distinct. Fracture subconchoidal to uneven. Brittle. H. = 6–6·5. G. = 3·1–3·2. Luster vitreous to resinous. Color white, light yellow, honey-yellow to chestnut-brown and garnet- or hyacinth-red. Pleochroism sometimes distinct. Optically +.

Chondrodite. Absorption $X > Z > Y$. Optically +. Ax. pl. and $Bx_a \perp b$ (010). $Bx_o \wedge c$ axis $= X \wedge c$ axis $= +25° 52'$ Brewster; 28° 56′ Kafveltorp; 30° approx., Mte. Somma. $\beta = 1·619$; $\gamma - \alpha = 0·031$. 2V = 80°.

Humite. Ax. pl. ∥ *c* (001). Bx ⊥ *a* (100). $\beta = 1·643$. $\gamma - \alpha = 0·035$.

Clinohumite. Ax. pl. and $Bx_a \perp b$ (010). $Bx_o \wedge c$ axis $= +11°–12°$; 7½° approx., Brewster. 2V = 76°. $\beta = 1·670$. $\gamma - \alpha = 0·038$.

902



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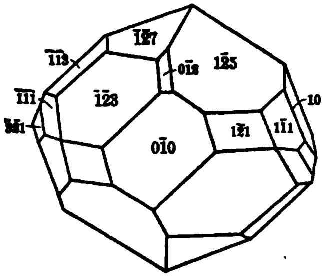

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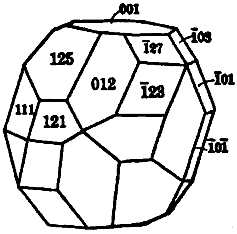
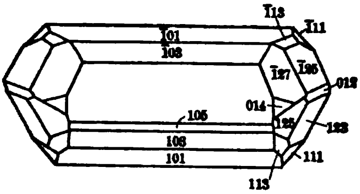


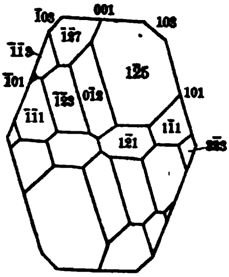
Figs. 902, 903, *Chondrodite*, Brewster, N. Y. *Chondrodite*, Sweden

905



Projection on (001)

906



Projection on (01̄0)

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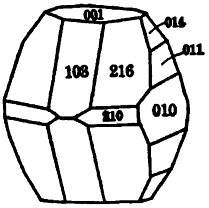
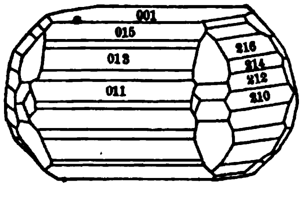


Figs. 905, 906, *Chondrodite*, Mte. Somma *Humite*, Sweden

908



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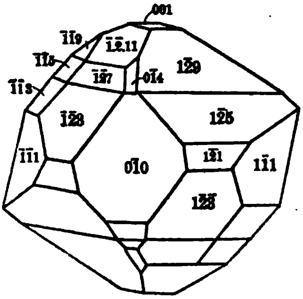

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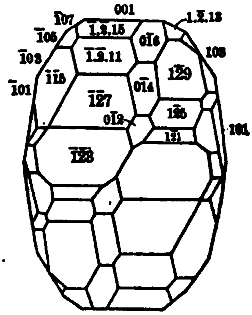


Projection on (01̄0)

Humite, Vesuvius *Clinohumite*, Brewster *Clinohumite*, Mte. Somma

Comp. — Basic fluosilicates of magnesium with related formulas as shown in the table above. Hydroxyl replaces part of the fluorine, and iron often takes the place of magnesium.

Pyr., etc. — B.B. infusible; some varieties blacken and then burn white. Fused with potassium bisulphate in the closed tube gives a reaction for fluorine. With the fluxes a reaction for iron. Gelatinizes with acids. Heated with sulphuric acid gives off silicon fluoride.

Obs. – Chondrodite, humite, and clinohumite all occur at Vesuvius in the ejected masses both of limestone or feldspathic type found on Monte Somma. They are associated with chrysolite, biotite, pyroxene, magnetite, spinel, vesuvianite, calcite, etc.; also in often with sanidine, meionite, nephelite. Of the three species, humite is the rarest and clinohumite of most frequent occurrence. They seldom all occur together in the same mass, and only rarely two of the species (as humite and clinohumite) appear together. Occasionally clinohumite interpenetrates crystals of humite, and parallel intergrowths with chrysolite have also been observed.

Chondrodite occurs at Mte. Somma, Vesuvius, as above noted; at Pargas, Finland, honey-yellow in limestone; at Kafveltorp, Nya-Kopparberg, Sweden, associated with chalcopyrite, galena, sphalerite. At Brewster, N. Y., at the Tilly Foster magnetic iron mine in dark garnet-red crystals. Also probably at numerous points where the occurrence of "chondrodite" has been reported.

Humite also occurs at the Ladu mine near Filipstadt, Sweden, with magnetite in crystalline limestone. In crystalline limestone with clinohumite in Andalusia, Spain. Also in large, coarse, partly altered crystals at the Tilly Foster iron-mine at Brewster, N. Y. Noted at Franklin Furnace, N. J.

Clinohumite occurs at Mte. Somma and in Andalusia; in crystalline limestone near Lake Baikal in East Siberia; at Brewster, N. Y., in rare but highly modified crystals.

Hydroclinohumite is a titaniferous variety (originally called *titanolivine*) from Ala Valley, Piedmont, Italy.

Prolectite is from the Ko mine, Nordmark, Sweden; very rare; imperfectly known.

Numerous other localities of "chondrodite" have been noted, chiefly in crystalline limestone; most of them are probably to be referred to the species chondrodite, but the identity in many cases is yet to be proved. At Brewster large quantities of massive "chondrodite" occur associated with magnetite, enstatite, ripidolite, and from its extensive alteration serpentine has been formed on a large scale. The granular mineral is common in limestone in Sussex Co., N. J., and Orange Co., N. Y., associated with spinel, and occasionally with pyroxene and corundum. Also in Mass., at Chelmsford, with scapolite at South Lee, in limestone. In Canada, in limestone at St. Jerome, Grenville, etc., abundant.

The name chondrodite is from χόνδρος, *a grain*, alluding to the granular structure. Humite is from Sir Abraham Hume.

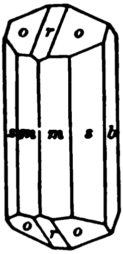
Leucophœnicite. $Mn_5(MnOH)_2(SiO_4)_2$, similar to the humite type of formula. Monoclinic. In striated crystals elongated parallel to ortho-axis. Massive. H. = 5·5–6. G. = 3·8. Color light purplish red. Fusible. From Franklin, N. J.

ILVAITE. Lievrite. Yenite.

Orthorhombic. Axes $a : b : c = 0{\cdot}6665 : 1 : 0{\cdot}4427$.

mm''', 110 ∧ 1$\bar{1}$0 = 67° 22'. *rr'*, 101 ∧ $\bar{1}$01 = 67° 11'.
ss', 120 ∧ $\bar{1}$20 = 73° 45'. *oo'*, 111 ∧ $\bar{1}$11 = 62° 33'.

911



Commonly in prisms, with prismatic faces vertically striated. Columnar or compact massive.

Cleavage: *b* (010), *c* (001) rather distinct. Fracture uneven. Brittle. H. = 5·5–6. G. = 3·99–4·05. Luster submetallic. Color iron-black or dark grayish black. Streak black, inclining to green or brown. Opaque.

Comp. — $CaFe_2(FeOH)(SiO_4)_2$ or $H_2O.CaO.4FeO.Fe_2O_3.4SiO_2$ = Silica 29·3, iron sesquioxide 19·6, iron protoxide 35·2, lime 13·7, water 2·2 = 100. Manganese may replace part of the ferrous iron.

Pyr., etc. — B.B. fuses quietly at 2·5 to a black magnetic bead. With the fluxes reacts for iron. Some varieties give also a reaction for manganese. Gelatinizes with hydrochloric acid.

Obs. — Found on Elba in dolomite; on Mt. Mulatto near Predazzo, Tyrol, Austria, in granite; Schneeberg, Saxony; Fossum, in Norway. In crystals from Siorarsiut, South Greenland. Reported as formerly found at Cumberland, R. I.; also at Milk Row quarry, Somerville, Mass. In fine crystals from South Mountain mine, Owyhee Co., Idaho. Named *Ilvaite* from the Latin name of the island (Elba).

Ardennite. Dewalquite. A vanadio-silicate of aluminium and manganese; also containing arsenic. In prismatic crystals resembling ilvaite. H. = 6–7. G. = 3·620. Yellow to yellowish brown. Index about 1·79. Found at Salm Château in the Ardennes, Belgium.

Långbanite. Manganese silicate with ferrous antimonate; formula doubtful. Rhombohedral-tetartohedral. In iron-black hexagonal prismatic crystals. H. = 6·5. G. = 4·918. Luster metallic. From Långban, Sweden.

The following are rare lead silicates. See also p. 498.

Kentrolite. Probably $3PbO.2Mn_2O_3.3SiO_2$. In minute prismatic crystals; often in sheaf-like forms; also massive. H. = 5. G. = 6·19. Color dark reddish brown; black on the surface. From southern Chile; Långban and Jakobsberg, Sweden; Bena Padru, near Ozieri, Sardinia.

Melanotekite. $3PbO.2Fe_2O_3.3SiO_2$ or $(Fe_4O_3)Pb_3(SiO_4)_3$. Orthorhombic; prismatic. Massive; cleavable. H. = 6·5. G. = 5·73. Luster metallic to greasy. Color black to blackish gray. Occurs with native lead at Långban, Sweden. Also in crystals resembling kentrolite at Hillsboro, N. M.

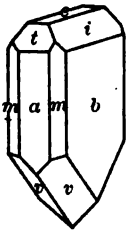
Bertrandite. $H_2Be_4Si_2O_9$ or $H_2O.4BeO.2SiO_2$. Orthorhombic-hemimorphic. In small tabular or prismatic crystals. H. = 6–7. G. = 2·59–2·60. Colorless to pale yellow. Optically –. β = 1·603. Usually occurs in feldspathic veins, often with other beryllium minerals as a result of the alteration of beryl. At the quarries of Barbin near Nantes, France; Pisek, Bohemia; Irkutka Mt., Altai Mts., Russia; Iveland, Southern Norway; Cornwall, England; Mt. Antero, Chaffee Co., Col., with phenacite; Amelia Court-House, Va.; Oxford Co., Me.

CALAMINE. Smithsonite. Hemimorphite.

Orthorhombic-hemimorphic. Axes $a : b : c$ = 0·7834 : 1 : 0·4778.

mm''', $110 \wedge 10\bar{1}$ = 76° 9'.
ss', $101 \wedge \bar{1}01$ = 62° 46'.
tt', $301 \wedge \bar{3}01$ = 122° 41'.
ee', $011 \wedge 0\bar{1}1$ = 51° 5'.
ii', $031 \wedge 0\bar{3}1$ = 110° 12'.
vv''', $121 \wedge 1\bar{2}1$ = 78° 26'.

912



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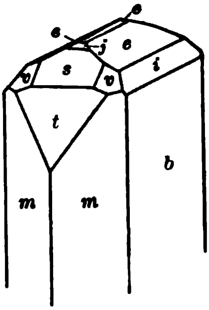


Crystals often tabular || *b* (010); also prismatic; faces *b* vertically striated. Usually implanted and showing one extremity only. Often grouped in sheaf-like forms and forming drusy surfaces in cavities. Also stalactitic, mammillary, botryoidal, and fibrous forms; massive and granular.

Cleavage: *m* (110) perfect; *s* (101) less so; *c* (001) in traces. Fracture uneven to subconchoidal. Brittle. H. = 4·5–5, the latter when crystallized. G. = 3·40–3·50. Luster vitreous; *c* (001) subpearly, sometimes adamantine. Color white; sometimes with a delicate bluish or greenish shade; also yellowish to brown. Streak white. Transparent to translucent. Optically +. 2V = 46°. α = 1·614. β = 1·617. γ = 1·636. Strongly pyroelectric.

Comp. — H_2ZnSiO_5 or $(ZnOH)_2SiO_3$ or $H_2O.2ZnO.SiO_2$ = Silica 25·0, zinc oxide 67·5, water 7·5 = 100. The water goes off only at a red heat; unchanged at 340° C.

Pyr., etc. — In the closed tube decrepitates, whitens, and gives off water. B.B. almost infusible (F. = 6). On charcoal with soda gives a coating which is yellow while hot, and white on cooling. Moistened with cobalt solution, and heated in O.F., this coating assumes a bright green color, but the ignited mineral itself becomes blue. Gelatinizes with acids even when previously ignited.

Diff. — Characterized by its infusibility; reaction for zinc; gelatinization with acids. Resembles some smithsonite (which effervesces with acid), also prehnite.

Obs. — Calamine and smithsonite are usually found associated in veins or beds in stratified calcareous rocks accompanying sulphides of zinc, iron and lead. Thus at Aix-la-Chapelle, Germany; Raibel and Bleiberg, in Carinthia; Moresnet in Belgium; Rezbánya and Schemnitz, Hungary. At Roughten Gill, in Cumberland; at Alston Moor, which near Matlock, in Derbyshire; Leadhill, Scotland; at Nerchinsk, in eastern Siberia. From Santa Eulalia, Chihuahua, Mexico.

In the United States occurs at Sterling Hill, near Ogdensburg, N. J., in fine clear crystalline masses. In Pa., at the Perkiomen and Phenixville lead mines; at Friedensville. Abundant in Va., at Austin's mines in Wythe Co. With the zinc deposits of southwestern Missouri, especially about Granby, both as crystallized and massive calamine. Crystals from Leadville, Col.; from Organ Mts., N. M.; Elkhorn Mts., Mon. At the Emma mine, Cottonwood Cañon, Utah.

The name *Calamine* (with *Galmei* of the Germans) is commonly supposed to be a corruption of *Cadmia*. Agricola says it is from *calamus*, a *reed*, in allusion to the slender forms (stalactitic) common in the *cadmia fornacum*.

Use. — An ore of zinc.

Clinohedrite. $H_2CaZnSiO_5$. Monoclinic-clinohedral (see Figs. 352, 353, p. 138). H. = 5·5. G. = 3·33. Colorless or white to amethystine. Index, 1·67. From Franklin, N. J.

Stokesite. — Perhaps $H_4CaSnSi_3O_{11}$. Orthorhombic. Prismatic cleavage. H. = 6. G. = 3·2. Colorless. β = 1·61. From Roscommon Cliff, St. Just, Cornwall.

Carpholite. $H_4MnAl_2Si_2O_{10}$. In radiated and stellated tufts. G. = 2·935. Color straw- to wax-yellow. Biaxial, —. β = 1·63. Occurs at the tin mines of Schlaggenwald, Bohemia; Wippra, in the Harz Mts., on quartz, etc.

Lawsonite. $H_4CaAl_2Si_2O_{10}$. In prismatic orthorhombic crystals; *mm'''*, 110 ∧ $1\bar{1}0$ = 67° 16'. G. = 3·09. Luster vitreous to greasy. Colorless, pale blue to grayish blue. Optically +. β = 1·669. Occurs in crystalline schists of the Tiburn peninsula, Marin Co., Cal.; also in the schists of Pontgibaud, France, and New Caledonia.

Hibschite. Same as for *lawsonite*, $H_4CaAl_2Si_2O_{10}$. In minute isometric crystals, usually octahedrons. H. = 6. G. = 3·0. Colorless or pale yellow. Refractive index, 1·67. Infusible. From the phonolite of Marienberg, Bohemia. Associated with melanite.

Cerite. A silicate of the cerium metals chiefly, with water. Crystals rare; commonly massive; granular. H. = 5·5. G. = 4·86. Color between clove-brown and cherry-red to gray. Indices, 1·83–1·93. Occurs at Bastnäs, near Riddarhyttan, Sweden.

Toernebohmite. A silicate of the cerium metals, chiefly, $R_3(OH)(SiO_4)_2$. Monoclinic? Color, green to olive. β = 1·81. Biaxial, +. Strong dispersion, $\rho < v$. Pleochroic, rose to blue-green. From Bastnäs, near Riddarhyttan, Sweden.

Beckelite. $Ca_3(Ce,La,Di)_4Si_3O_{15}$. Isometric. Crystals small, often microscopic. Cubic cleavage. H. = 5. G. = 4·1. Color yellow. Infusible. Occurs with nepheline syenite rocks near Mariupol, Russia.

Hellandite. A basic silicate chiefly of the cerium metals, aluminium, manganese and calcium. Monoclinic. Prismatic habit. H. = 5·5. G. = 3·7. Color brown. Fusible. Found in pegmatite near Kragerö, Norway.

Bazzite. A silicate of scandium with other rare earth metals, iron and a little soda. Hexagonal. In minute prisms, often barrel shaped. H. = 6·5. G. = 2·8. Color azure-blue. Transparent in small individuals. Optically —. Refractive indices, ω = 1·626. ϵ = 1·605. Strongly dichroic, ω = pale greenish yellow, ϵ = azure-blue. Infusible. Insoluble in ordinary acids. Found at Baveno, Italy.

ANGARALITE. $2(Ca,Mg)O.5(Al,Fe)_2O_3.6SiO_2$. In thin tabular hexagonal(?) crystals. G. = 2·62. Color black from carbonaceous impurities. Uniaxial, +. In contact zone of limestone, southern part of Yenisei District, Siberia.

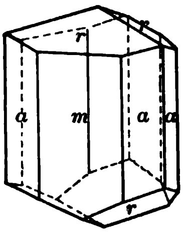
TOURMALINE.

Rhombohedral-hemimorphic. Axis *c* = 0·4477.

cr, 0001 ∧ $10\bar{1}1$ = 27° 20'. *rr'*, $10\bar{1}1$ ∧ $\bar{1}101$ = 46° 52'. *uu'*, $32\bar{5}1$ ∧ $\bar{3}5\bar{2}1$ = 66° 1'.
co, 0001 ∧ $02\bar{2}1$ = 45° 57'. *oo'*, $02\bar{2}1$ ∧ $\bar{2}021$ = 77° 0'. *uu*^{v}, $32\bar{5}1$ ∧ $5\bar{3}\bar{2}1$ = 42° 36'.

Crystals usually prismatic in habit, often slender to acicular; rarely flattened, the prism nearly wanting. Prismatic faces strongly striated vertically, and the crystals hence often much rounded to barrel-shaped. The cross-section of the prism three-sided (*m*, Fig. 921), six-sided (*a*), or nine-sided (*m* and *a*). Crystals commonly hemimorphic. Sometimes isolated, but more commonly in parallel or radiating groups. Sometimes massive compact; also columnar, coarse or fine, parallel or divergent.

914



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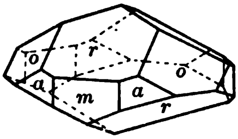

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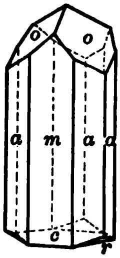

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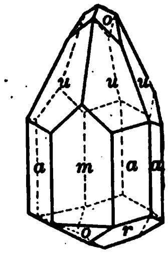

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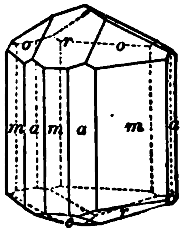

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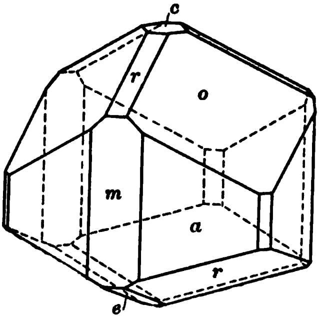

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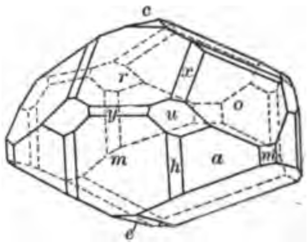

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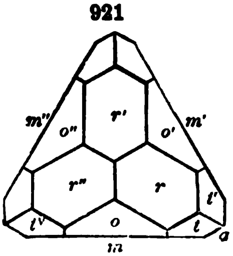


Cleavage: *a* (11$\bar{2}$0), *r* (10$\bar{1}$1) difficult. Fracture subconchoidal to uneven. Brittle and often rather friable. H. = 7–7·5. G. = 2·98–3·20. Luster vitreous to resinous. Color black, brownish black, bluish black, most common; blue, green, red, and sometimes of rich shades; rarely white or colorless; some specimens red internally and green externally; and others red at one extremity, and green, blue or black at the other; the zonal arrangement of different colors widely various both as to the colors and to crystallographic directions. Streak uncolored. Transparent to opaque.

Strongly dichroic, especially in deep-colored varieties; axial colors varying widely. Absorption for ω much stronger than for ϵ, thus sections || *c* axis transmit sensibly the extraordinary ray only, and hence their use (*e.g.*, in the tourmaline tongs (p. 243)) for giving polarized light. Exhibits idiophanous figures (p. 288). Optically —. Birefringence rather high, $\omega - \epsilon = 0{\cdot}02$. Indices: $\omega_y = 1{\cdot}6366$, $\epsilon_y = 1{\cdot}6193$ colorless variety; $\omega_r = 1{\cdot}6435$, $\epsilon_r = 1{\cdot}6222$ blue-green. Sometimes abnormally biaxial. Becomes electric by friction; also strongly pyroelectric.

Var. — *Ordinary.* In crystals as above described; black much the most common. (*a*) *Rubellite;* the red, sometimes transparent; the Siberian is mostly violet-red (*siberite*), the Brazilian rose-red; that of Chesterfield and Goshen, Mass., pale rose-red and opaque; that of Paris, Me., fine ruby-red and transparent. (*b*) *Indicolite*, or *indigolite;* the blue, either pale or bluish black; named from the indigo-blue color. (*c*) *Brazilian Sapphire* (in jewelry); Berlin-blue and transparent. (*d*) *Brazilian Emerald*, *Chrysolite* (or *Peridot*) *of Brazil;* green and transparent. (*e*) *Peridot of Ceylon;* honey-yellow. (*f*) *Achroite;* colorless tourmaline, from Elba. (*g*) *Aphrizite;* black tourmaline, from Kragerö, Norway. (*h*) *Columnar* and *black;* coarse columnar. Resembles somewhat common hornblende, but has a more resinous fracture, and is without distinct cleavage or anything like a fibrous appearance in the texture; it often has the appearance on a broken surface of some kinds of soft coal.

Comp. — A complex silicate of boron and aluminium, with also either magnesium, iron or the alkali metals prominent. A general formula may be written as $H_9Al_3(B.OH)_2Si_4O_{19}$ (Penfield and Foote) in which the hyrogen may be replaced by the alkalies and also the bivalent elements, Mg,Fe,Ca. Fluorine is commonly present in small amounts.

The varieties based upon composition fall into three prominent groups, between which there are many gradations:

1. ALKALI TOURMALINE. Contains sodium or lithium, or both; also potassium. G. = 3·0–3·1. Color red to green; also colorless. From pegmatites.

2. IRON TOURMALINE. G. = 3·1–3·2. Color usually deep black. Accessory mineral in siliceous igneous rocks and in mica schists, etc.

3. MAGNESIUM TOURMALINE. G. = 3·0–3·09. Usually yellow-brown to brownish black; also colorless. From limestone or dolomite.

A *chromium tourmaline* also occurs. G. = 3·120. Color dark green.

Pyr., etc. — The magnesia varieties fuse rather easily to a white blebby glass or slag; the iron-magnesia varieties fuse with a strong heat to a blebby slag or enamel; the iron varieties fuse with difficulty, or, in some, only on the edges; the iron-magnesia-lithia varieties fuse on the edges, and often with great difficulty, and some are infusible; the lithia varieties are infusible. With the fluxes many varieties give reactions for iron and manganese. Fused with a mixture of potassium bisulphate and fluor-spar gives a distinct reaction for boric acid. Not decomposed by acids. Crystals, especially of the lighter colored varieties, show strong pyroelectricity.

Diff. — Characterized by its crystallization, prismatic forms usual, which are three-, six-, or nine-sided, and often with rhombohedral terminations; massive forms with columnar structure; also by absence of cleavage (unlike amphibole and epidote); in the common black kinds by the coal-like fracture; by hardness; by difficult fusibility (common kinds), compared with garnet and vesuvianite. The boron test is conclusive.

Micro. — Readily distinguished in thin sections by its somewhat high relief; rather strong interference-colors; negative uniaxial character; decided colors in ordinary light in which basal sections often exhibit a zonal structure. Also, especially, by its remarkable absorption when the direction of crystal elongation is ⊥ to the vibration-plane of the lower nicol; this with its lack of cleavage distinguishes it from biotite and amphibole, which alone among rock-making minerals show similar strong absorption.

Obs. — Commonly found in granite and gneisses as a result of fumarole action or of mineralizing gases in the fluid magma, especially in the pegmatite veins associated with such rocks; at the periphery of such masses or in the schists, or altered limestones, gneisses, etc., immediately adjoining them. It marks especially the boundaries of granitic masses, and its associate minerals are those characteristic of such occurrences; quartz, albite, microcline, muscovite, etc. The variety in granular limestone or dolomite is commonly brown; the bluish-black variety sometimes associated with tin ores; the brown with titanium; the lithium variety is often associated with lepidolite. Red or green varieties, or both, occur near Ekaterinburg in the Ural Mts.; Elba; Campolongo in Tessin, Switzerland; Penig, Saxony; also the province Minas Geraes, Brazil; yellow and brown from Ceylon; dark brown varieties from Eibenstock, Saxony; the Zillertal, Tyrol, Austria; black from Arendal, Norway; Snarum and Kragerö, Norway; pale yellowish brown at Windisch Kappel in Carinthia; fine black crystals occur in Cornwall at different localities. Variously colored from Madagascar.

In the United States, in Me. at Paris and Hebron, magnificent red and green tourmalines with lepidolite, etc.; also blue and pink varieties; and at Norway; pink at Rumford, embedded in lepidolite; at Auburn in clear crystals of a delicate pink or lilac with lepidolite, etc.; at Albany, green and black. In Mass., at Chesterfield, red, green, and blue; at Goshen, blue and green; at Norwich, New Braintree and Carlisle, good black crystals. In N. H., Grafton, Acworth; at Orford, brownish black in steatite. In Conn., at Monroe, dark brown in mica-slate; at Haddam, black in mica slate; also fine pink and green; at New Milford, black. In N. Y., near Gouverneur, brown crystals, with tremolite, etc., in granular limestone; black near Port Henry, Essex Co.; near Edenville; splendid black crystals at Pierrepont, St. Lawrence Co.; colorless and glassy at De Kalb; dark brown at McComb. In N. J., at Hamburg and Newton, black and brown crystals in limestone, with spinel; also grass-green crystals in crystalline limestone near Franklin Furnace. In Pa., at Newlin, Chester Co.; near Unionville, yellow; at Chester, fine black; Middletown, black; Marple, green in talc; near New Hope on the Delaware, large black crystals. A chrome variety from the chromite beds in Montgomery Co., Md. In N. C., Alexander Co., in fine black crystals with emerald and hiddenite. In Cal., fine groups of rubellite in lepidolite from Mesa Grande, Pala, etc. in San Diego Co.

In Canada, in the province of Quebec, yellow crystals in limestone at Calumet Falls, Litchfield, Pontiac Co.; at Hunterstown; fine brown crystals at Clarendon, Pontiac Co.; black at Grenville and Argenteuil, Argenteuil Co. In Ontario, in fine crystals at North Burgess, Lanark Co.; Galway and Stoney Lake in Dummer, Peterborough Co.

The name *turmalin* from *Turamali* in Cingalese (applied to zircon by jewelers of Ceylon) was introduced into Holland in 1703, with a lot of gems from Ceylon.

Use. — The variously colored and transparent varieties are used as gem stones; see under "Var." above.

Dumortierite. A basic aluminium borosilicate, perhaps $8Al_2O_3.B_2O_3.6SiO_2.H_2O$ (Schaller). The water and boric oxide have been considered as variable in amount and basic in character with the general formula, $(AlO)_{16}Al_4(SiO_4)_7$ (Ford).

Orthorhombic. Prismatic angle approximately 60°. Usually in fibrous to columnar aggregates. Cleavage: *a* (100), distinct; also prismatic, imperfect. H. = 7. G. = 3·26–3·36. Luster vitreous. Color bright smalt-blue to greenish blue. Transparent to translucent. Pleochroism very strong: *X* deep-blue or nearly colorless, *Y* yellow to red-violet or nearly colorless, *Z* colorless or pistachio-green. Exhibits idiophanous figures, analogous to andalusite. Optically −. Ax. pl. ∥ *b* (010). Bx ⊥ *c* (001). $\alpha = 1{\cdot}678$. $\beta = 1{\cdot}686$. $\gamma = 1{\cdot}689$.

Recognized in thin section by its rather high relief; low interference-colors (like those of quartz); occurrence in slender prisms, needles or fibers, with negative optical extension; parallel extinction; biaxial character and especially by its remarkable pleochroism.

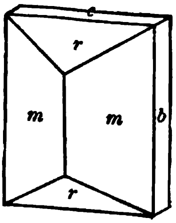
Found embedded in feldspar in blocks of gneiss at Chaponost, near Lyons, France; from Wolfshau, near Schmiedeberg, Silesia; in the iolite of the gneiss of Tvedestrand, Norway; Rio de Janeiro, Brazil. In the United States, it occurs near Harlem, New York Island, in the pegmatoid portion of a biotite-gneiss; in a quartzose rock at Clip, Yuma Co., Arizona; from San Diego Co., Cal.; Woodstock, Wash.

STAUROLITE. Staurotide.

Orthorhombic. Axes $\underset{\cdot}{a} : b : c = 0{\cdot}4734 : 1 : 0{\cdot}6828$.

mm''', $110 \wedge 1\bar{1}0 = 50° 40'$.
rr', $101 \wedge \bar{1}01 = 110° 32'$.
cr, $001 \wedge 101 = 55° 16'$.
mr, $110 \wedge 101 = 42° 2'$.

922



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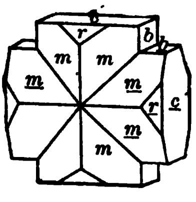

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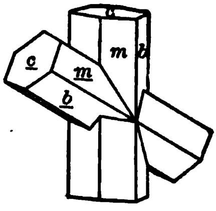
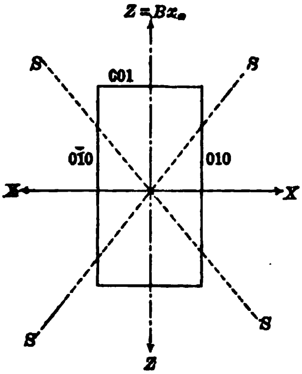


Twins cruciform: tw. pl. *x* (032), the crystals crossing nearly at right angles; tw. pl. *z* (232), crossing at an angle of 60° approximately; tw. pl.

y (230) rare, also in repeated twins (cf. Figs. 397, p. 164; 439, 440, 441, p. 170). Crystals commonly prismatic and flattened || *b* axis; often with rough surfaces.

Cleavage: *b* (010) distinct, but interrupted; *m* (110) in traces. Fracture subconchoidal. Brittle. H. = 7–7·5. G. = 3·65–3·77. Subvitreous, inclining to resinous. Color dark reddish brown to brownish black, and yellowish brown. Streak uncolored to grayish. Translucent to nearly or quite opaque. Pleochroism distinct: *Z* (= *c* axis) hyacinth-red to blood-red, *X*, *Y* yellowish red; or *Z* gold-yellow, *X*, *Y* light yellow to colorless. Optically +. Ax. pl. || *a* (100). Bx ⊥ *c* (001). 2V = 88° (approx.). $\alpha = 1{\cdot}736$. $\beta = 1{\cdot}741$. $\gamma = 1{\cdot}746$.

925



Comp. — $HFeAl_5Si_2O_{13}$, which may be written $(AlO)_4(AlOH)Fe(SiO_4)_2$ or $H_2O.2FeO.5Al_2O_3.4SiO_2$ = Silica 26·3, alumina 55·9, iron protoxide 15·8, water 2·0 = 100. Magnesium (also manganese) replaces a little of the ferrous iron; ferric iron part of the aluminium.

Nordmarkite from Nordmark, Sweden, contains manganese in large amounts.

Pyr., etc. — B.B. infusible, excepting the manganesian variety, which fuses easily to a black magnetic glass. With the fluxes gives reactions for iron, and sometimes for manganese. Imperfectly decomposed by sulphuric acid.

Diff. — Characterized by the obtuse prism (unlike andalusite, which is nearly square); by the frequency of twinning forms; by hardness and infusibility.

Micro. — Under the microscope, sections show a decided color (yellow to red or brown) and strong pleochroism (yellow and red); also characterized by strong refraction (high relief), rather bright interference-colors, parallel extinction and biaxial character (generally positive in the direction of elongation). Easily distinguished from rutile (p. 427) by its biaxial character and lower interference-colors.

Obs. — Usually found in crystalline schists, as mica schist, argillaceous schist, and gneiss, as a result of regional or contact metamorphism; often associated with garnet, sillimanite, cyanite, and tourmaline. Sometimes encloses symmetrically arranged carbonaceous impurities like andalusite (p. 524). Other impurities are also often present, especially silica, sometimes up to 30 to 40 p. c.; also garnet, mica, and perhaps magnetite, brookite.

Occurs with cyanite in paragonite schist, at Mt. Campione, Switzerland; in the Zillertal, Tyrol, Austria; Goldenstein in Moravia; Aschaffenburg, Bavaria; in large twin crystals in the mica schists of Brittany and Scotland. In the province of Minas Geraes, Brazil.

Abundant throughout the mica schists of New England. In Me., at Windham. In N. H., brown at Franconia; at Lisbon; on the shores of Mink Pond, loose in the soil. In Mass., at Chesterfield, in fine crystals. In Conn., at Bolton, Vernon, etc.; Southbury with garnets; at Litchfield, black crystals. In N. C., near Franklin, Macon Co.; also in Madison and Clay counties. In Ga., in Fannin Co., loose in the soil in fine crystals. In large crystals from Ducktown, Tenn.

Named from *σταυρός, a cross.*

Use. — Occasionally a transparent stone is cut for a gem.

Kornerupine. Near $MgAl_2SiO_6$. In fibrous to columnar aggregates, resembling sillimanite. H. = 6·5. G. = 3·273 kornerupine; 3·341 prismatine. Colorless to white, or brown. Biaxial, −. Indices, 1·669–1·682.

Kornerupine occurs at Fiskernäs on the west coast of Greenland. *Prismatine* is from Waldheim, Saxony. Found in large clear crystals of a sea-green color and gem quality from near Betroka, Madagascar.

Sapphirine. $Mg_5Al_{12}Si_2O_{27}$. In indistinct tabular crystals. Usually in disseminated grains, or aggregations of grains. H. = 7·5. G. = 3·42–3·48. Color pale to dark blue or green. Biaxial, −. Indices, 1·705–1·711. From Fiskernäs, southwestern Greenland. Occurs near Betroka, Madagascar. From St. Urbain, Quebec.

Grandidierite. A basic silicate of aluminium, ferric iron, magnesium, ferrous iron, etc. Orthorhombic. In elongated crystals. Two cleavages. G. = 3·0. Color bluish green.

$\beta = 1{\cdot}64$. Strongly pleochroic. Found in pegmatite at Andrahomana in southern Madagascar.

Serendibite. $10(Ca,Mg)O.5Al_2O_3.B_2O_3.6SiO_2$. In irregular grains showing polysynthetic twinning; probably monoclinic or triclinic. H. = 6·7. G. = 3·4. Color blue. Pleochroism marked. Refractive index, 1·7. Infusible. From Gangapitiya near Ambakotte, Ceylon.

Silicomagnesiofluorite. A fluosilicate of calcium and magnesium, perhaps, $H_2Ca_4Mg_3Si_2O_7F_{10}$. Radiating fibrous in spherical forms. H. = 2·5. G. = 2·9. Color ash-gray, light greenish or bluish. Fusible. From Lupikko, near Pitkäranta, Finland.

Grothine. A silicate of calcium with aluminium and a little iron of uncertain composition. Orthorhombic. In small tabular crystals. Colorless. Transparent. G. = 3·09. Optically +. Infusible. Decomposed by sulphuric acid. Found with *microsommite* on limestone near Nocera and Sarno, Campagna, Italy.

ALOISIITE. Luigite. A basic silicate containing ferrous oxide, lime, magnesia, and soda. Amorphous. Color, brown to violet. Acts as a cement in a tuff found at Fort Portal, Uganda.

PÖCHITE. $H_{16}Fe_8Mn_2Si_3O_{29}$. Amorphous. H. = 3·5–4. G. = 3·70. Color reddish brown. Opaque. Found in iron ore near Vareš, Bosnia.

SILICATES

Section B. Chiefly Hydrous Species

The SILICATES of this second section include the true hydrous compounds, that is, those which contain water of crystallization, like the zeolites; also the hydrous amorphous species, as the clays, etc. There are also included certain species — as the Micas, Talc, Kaolinite — which, while they yield water upon ignition, are without doubt to be taken as acid or basic metasilicates, orthosilicates, etc. Their relation, however, is so close to other true hydrous species that it appears more natural to include them here than to have placed them in the preceding chapter with other acid and basic salts. Finally, some species are referred here about whose chemical constitution and the part played by the water present there is still much doubt. The divisions recognized are as follows:

I. Zeolite Division

1. *Introductory Subdivision.* 2. *Zeolites*

II. Mica Division

1. *Mica Group.* 2. *Clintonite Group.* 3. *Chlorite Group*

III. Serpentine and Talc Division

Chiefly Silicates of Magnesium.

IV. Kaolin Division

Chiefly Silicates of Aluminium; for the most part belonging to the group of the clays.

V. Concluding Division

Species not included in the preceding divisions; chiefly silicates of the heavy metals, iron, manganese, etc.

I. Zeolite Division

1. *Introductory Subdivision*

Of the species here included, several, as Apophyllite, Okenite, etc., while not strictly Zeolites, are closely related to them in composition and method of occurrence. Pectolite (p. 483) and Prehnite (p. 534) are also sometimes classed here.

Inesite. $H_2(Mn,Ca)_6Si_6O_{19}.3H_2O$. Crystals small, prismatic; also fibrous, radiated and spherulitic. H. = 6. G. = 3·029. Color rose- to flesh-red. Occurs at the manganese mines near Dillenburg, Germany. *Rhodotilite* is the same species from the Harstig mine, Pajsberg, Sweden. From Jakobsberg and Långban, Sweden; Villa Corona, Durango, Mexico.

Hillebrandite. $Ca_2SiO_4.H_2O$. Orthorhombic; radiating fibrous. H. = 5·5. G. = 2·7. Refractive index = 1·61. Color white. Fusible with difficulty. Found in contact zone between limestone and diorite in the Velardeña mining district, Mexico.

Crestmoreite. Probably $4H_2CaSiO_4.3H_2O$. Compact. Color, snow-white. H. = 3. G. = 2·2. β = 1·59. An alteration product of *Wilkeite*. From Crestmore, Riverside Co., Cal.

Riversideite. $2CaSiO_3.H_2O$. In compact fibrous veinlets. Silky luster. H. = 3. G. = 2·64. Indices, 1·59–1·60. Easily fusible. From Crestmore, Riverside Co., Cal.

Ganophyllite. $7MnO.Al_2O_3.8SiO_2.6H_2O$. In short prismatic crystals; also foliated, micaceous. Color brown. H. = 4–4·5. G. = 2·84. Biaxial, –. Indices, 1·705–1·730. From the Harstig mine, near Pajsberg, Sweden.

Lotrite. $3(Ca,Mg)O.2(Al,Fe)_2O_3.4SiO_2.2H_2O$. Massive, in an aggregate of small grains and leaves. One cleavage. H. = 7·5. G. = 3·2. Color green. Refractive index, 1·67. Found in small veins in a chlorite schist in the valley of the Lotru, Transylvania.

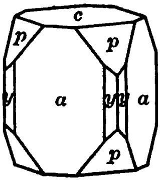
Okenite. $H_2CaSi_2O_6.H_2O$. Commonly fibrous; also compact. H. = 4·5–5. G. = 2·28–2·36. Color white, with a shade of yellow or blue. Biaxial, –. Index, 1·556. Occurs in basalt or related eruptive rocks; as in the Faroe Islands; Iceland; Disko, Niorkornat, etc., Greenland; Poona, India. From Crestmore, Riverside Co., Cal.

Gyrolite. $H_2Ca_2Si_3O_9.H_2O$. Rhombohedral-tetartohedral. In white concretions, lamellar-radiate in structure. Optically –. ω = 1·56. From the Isle of Skye, with stilbite, laumontite, etc.; in India, etc. With apophyllite of New Almaden, California; also Nova Scotia. Found also at various places in Bohemia; from Scotland and the Faroe Islands; São Paulo, Brazil. *Reyerite* from Greenland is similar to gyrolite. *Zeophyllite* is a similar species which may be identical with gyrolite. Rhombohedral. In spherical forms with radiating foliated structure. Perfect basal cleavage. H. = 3. G. = 2·8. Color white. ω = 1·56. From various localities in Bohemia and elsewhere.

APOPHYLLITE.

Tetragonal. Axis c = 1·2515.

926



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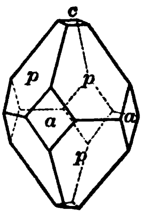

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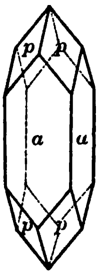

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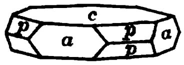


ay, 100 ∧ 310 = 18° 26′.
cp, 001 ∧ 111 = 60° 32′.

ap, 100 ∧ 111 = 52° 0′.
pp′, 111 ∧ $\bar{1}$11 = 76° 0′.

Habit varied; in square prisms (*a* (100)) usually short and terminated by *c* (001) or by *c* and *p* (111), and then resembling a cube or cubo-octahedron;

also acute pyramidal (*p* (111)) with or without *c* and *a*; less often thin tabular || *c*. Faces *c* often rough; *a* bright but vertically striated; *p* more or less uneven. Also massive and lamellar; rarely concentric radiated.

Cleavage: *c* (001) highly perfect; *m* (110) less so. Fracture uneven. Brittle. H. = 4·5–5. G. = 2·3–2·4. Luster of *c* pearly; of other faces vitreous. Color white, or grayish; occasionally with a greenish, yellowish, or rose-red tint, flesh-red. Transparent; rarely nearly opaque. Birefringence low; usually +, also –. Often shows anomalous optical characters (Art. **429**, Fig. 617). Indices, 1·535–1·537.

Comp. — $H_7KCa_4(SiO_3)_8.4\frac{1}{2}H_2O$ or $K_2O.8CaO.16SiO_2.16H_2O$ = Silica 53·7, lime 25·0, potash 5·2, water 16·1 = 100. A small amount of fluorine replaces part of the oxygen.

The above formula differs but little from $H_2CaSi_2O_6.H_2O$, in which potassium replaces part of the basic hydrogen. The form often accepted, $H_2(Ca,K)Si_2O_6.H_2O$, corresponds less well with the analyses.

Pyr., etc. — In the closed tube exfoliates, whitens, and yields water, which reacts acid. B.B. exfoliates, colors the flame violet (potash), and fuses to a white vesicular enamel. F. = 1·5. Decomposed by hydrochloric acid, with separation of slimy silica.

Diff. — Characterized by its tetragonal form, the square prism and pyramid the common habits; by the perfect basal cleavage and pearly luster on this surface.

Obs. — Occurs commonly as a secondary mineral in basalt and related rocks, with various zeolites, also datolite, pectolite, calcite; also occasionally in cavities in granite, gneiss, etc. Greenland, Iceland, the Faroe Islands, and British India, especially at Poonah, afford fine specimens of apophyllite in amygdaloidal basalt or diabase. Occurs also at Andreasberg, Harz Mts., Germany, of a delicate pink; Radautal in the Harz Mts.; at Orawitza, Hungary, with wollastonite; Utö, Sweden; on the Seisser Alp in Tyrol, Austria; Guanajuato, Mexico, often of a beautiful pink upon amethyst.

In the United States, large crystals occur at Bergen Hill, Paterson, West Paterson, and Great Notch, N. J.; in Pa., at the French Creek mines, Chester Co.; at the Cliff, Phœnix and other mines, Lake Superior region; Table Mt. near Golden, Col.; in Cal., at the mercury mines of New Almaden often stained brown by bitumen; also from Nova Scotia at Cape Blomidon, and other points.

Named by Haüy in allusion to its tendency to exfoliate under the blowpipe, from ἀπὸ and φύλλον, *a leaf*. Its whitish pearly aspect, resembling the eye of a fish after boiling, gave rise to the earlier name *Ichthyophthalmite*, from ἰχθύς, *fish*, ὀφθαλμός, *eye*.

2. Zeolites

The ZEOLITES form a family of well-defined hydrous silicates, closely related to each other in composition, in conditions of formation, and hence in mode of occurrence. They are often with right spoken of as analogous to the Feldspars, like which they are all silicates of aluminium with sodium and calcium chiefly, also rarely barium and strontium; magnesium, iron, etc., are absent or present only through impurity or alteration. Further, the composition in a number of cases corresponds to that of a hydrated feldspar; while fusion and slow recrystallization result in the formation from some of them of anorthite ($CaAl_2Si_2O_8$) or a calcium-albite ($CaAl_2Si_6O_{16}$) as shown by Doelter. The Zeolites do not, however, form a single group of species related in crystallization, like the Feldspars, but include a number of independent groups widely diverse in form and distinct in composition; chief among these are the monoclinic PHILLIPSITE GROUP; the rhombohedral CHABAZITE GROUP, and the orthorhombic (and monoclinic) NATROLITE GROUP. A transition in composition between certain end compounds has been more or less well-established in certain cases, but, unlike the Feldspars, with these species calcium and sodium seem to replace one another and an increase in alkali does not necessarily go with an increase in silica.

Like other hydrous silicates they are characterized by inferior hardness, chiefly from 3·5 to 5·5, and the specific gravity is also lower than with corresponding anhydrous species, chiefly 2·0 to 2·4. Corresponding to these characters; they are rather readily decomposed by acids, many of them with gelatinization. The intumescence B.B., which gives the name to the family (from *ζεῖν, to boil,* and *λίθος, stone*) is characteristic of a large part of the species.

The Zeolites are all secondary minerals, occurring most commonly in cavities and veins in basic igneous rocks, as basalt, diabase, etc.; less frequently in granite, gneiss, etc. In these cases the lime and the soda in part have been chiefly yielded by the feldspar; the soda also by elæolite, sodalite, etc.; potash by leucite, etc. The different species of the family are often associated together; also with pectolite and apophyllite (sometimes included with the zeolites), datolite, prehnite and, further, calcite. Many of the zeolites have been produced synthetically by various hydrochemical reactions. In general they appear to have been formed in nature by reactions upon the feldspar or feldspathoid minerals.

Ptilolite. $RAl_2Si_{10}O_{24}.5H_2O$. Here R = Ca : K_2 : Na_2 = 6 : 2 : 1 approx. In short capillary needles, aggregated in delicate tufts. Colorless, white. Biaxial, +. Indices, 1·480–1·485. Occurs upon a bluish chalcedony in cavities in a vesicular augite-andesite found in fragments in the conglomerate beds of Green and Table mountains, Jefferson Co., and from Silver Cliff, Custer Co., Col., also from Elba and Iceland.

Mordenite. $3RAl_2Si_{10}O_{24}.20H_2O$, where R = K_2 : Na_2 : Ca = 1 : 1 : 1. In minute crystals resembling heulandite in habit and angles; also in small hemispherical or reniform concretions with fibrous structure. H. = 3–4. G. = 2·15. Color white, yellowish or pinkish. Occurs near Morden, King's Co., Nova Scotia, in trap; also in western Wyoming near Hoodoo Mt., on the ridge forming the divide between Clark's Fork and the East Fork of the Yellowstone river. Also from Seiseralpe, Tyrol, Austria and the Faroe Islands.

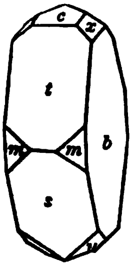
HEULANDITE. Stilbite *some authors.*

Monoclinic. Axes $a : b : c = 0·4035 : 1 : 0·4293$; $\beta = 88° 34\frac{1}{2}'$.

mm''', 110 ∧ $1\bar{1}0$ = 43° 56′. *cs*, 001 ∧ $\bar{2}01$ = 66° 0′.

ct, 001 ∧ 201 = 63° 40′. *cx*, 001 ∧ 021 = 40° $38\frac{1}{4}'$.

930



Crystals sometimes flattened || *b* (010), the surface of pearly luster (Fig. 930; also Fig. 21, p. 12); form often suggestive of the orthorhombic system. since the angles *cs* and *ct* differ but little. Also in globular forms; granular.

Cleavage: *b* (010) perfect. Fracture subconchoidal to uneven. Brittle. H. = 3·5–4. G. = 2·18–2·22. Luster of *b* strong pearly; of other faces vitreous. Color various shades of white, passing into red, gray and brown. Streak white. Transparent to subtranslucent. Optically +. Ax. pl. and $Bx_a \perp b$ (010). Ax. pl. and Bx_o for some localities nearly || *c* (001); also for others nearly ⊥ *c* in white light. $Bx_o \wedge c$ axis = $+57\frac{1}{2}°$. Axial angle variable, from 0° to 92°; usually $2E_r = 52°$. $\alpha = 1·498$. $\beta = 1·499$. $\gamma = 1·505$.

Comp. — $H_4CaAl_2(SiO_3)_6.3H_2O$ or $5H_2O.CaO.Al_2O_3.6SiO_2$ = Silica 59·2, alumina 16·8, lime 9·2, water 14·8 = 100.

Strontia is usually present, sometimes up to 3·6 p. c.

Pyr. — As with stilbite, p. 551.

Obs. — Heulandite occurs principally in basaltic rocks, associated with chabazite, stilbite and other zeolites; also in gneiss, and occasionally in metalliferous veins.

The finest specimens of this species come from Berufiord, and elsewhere in Iceland; the Faroe Islands; in British India, near Bombay; also in railroad cuttings in the Bhor and Thul Ghâts. Also occurs in the Kilpatrick Hills, near Glasgow; on the Island of Skye; Fassatal, Tyrol, Austria; Andreasberg, Harz Mts., Germany; Viesch and elsewhere, Switzerland.

In the United States, in diabase at Bergen Hill, West Paterson and Great Notch, N. J.; on north shore of Lake Superior; with haydenite at Jones's Falls near Baltimore (*beaumontite*), Md. At Peter's Point, Nova Scotia; also at Cape Blomidon, and other points.

Named after the English mineralogical collector, H. Heuland, whose cabinet was the basis of the classical work (1837) of Lévy.

Brewsterite. $H_4(Sr,Ba,Ca)Al_2(SiO_3)_6.3H_2O$. In prismatic crystals. H. = 5. G. = 2·45. Color white, inclining to yellow and gray. Biaxial, +. Index, 1·45. From Strontian in Argyleshire, Scotland; near Freiburg in Breisgau, Germany.

Epistilbite. Probably like heulandite, $H_4CaAl_2(SiO_3)_6.3H_2O$. Crystals monoclinic, uniformly twins; habit prismatic. In radiated spherical aggregations; also granular. G. = 2·25. Color white. Biaxial, −. Indices, 1·502–1·512. Occurs with scolecite at the Berufiord, Iceland; the Faroe Islands; Poona, India; in small reddish crystals, at Margaretville, Nova Scotia, etc. *Reissite* is from Santorin Island.

Phillipsite Group. Monoclinic

		$a : b : c$	β
Wellsite	$(Ba,Ca,K_2)Al_2Si_3O_{10}.3H_2O$	0·768 : 1 : 1·245	53° 27′
Phillipsite	$(K_2,Ca)Al_2Si_4O_{12}.4\frac{1}{2}H_2O$	0·7095 : 1 : 1·2563	55° 37′
Harmotome	$(K_2,Ba)Al_2Si_5O_{14}.5H_2O$	0·7032 : 1 : 1·2310	55° 10′
Stilbite	$(Na_2,Ca)Al_2Si_6O_{16}.6H_2O$	0·7623 : 1 : 1·1940	50° 50′

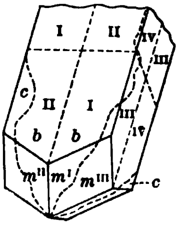
The above species, while crystallizing in the monoclinic system, are remarkable for the pseudo-symmetry exhibited by their twinned forms. Certain of these twins are pseudo-orthorhombic, others pseudo-tetragonal and more complex twins even pseudo-isometric.

Fresenius has shown that the species of this group may be regarded as forming a series, in which the ratio of RO : Al_2O_3 is constant (= 1 : 1), and that of SiO_2 : H_2O also chiefly 1 : 1. The end compounds assumed by him are:

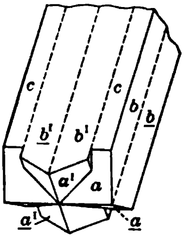
$$RAl_2Si_6O_{16}.6H_2O; \qquad R_2Al_4Si_4O_{16}.6H_2O.$$

Here R = Ca chiefly, in phillipsite and stilbite, Ba in harmotome, while in wellsite Ba, Ca, and K_2 are present; also in smaller amounts Na_2, Sr_2. The first of the above compounds may be regarded as a hydrated calcium albite, the second as a hydrated anorthite. Pratt and Foote, however, show that the anorthite end compound more probably has the formula $RAl_2Si_2O_8.2H_2O$ (or this doubled). The formulas given beyond are those corresponding to reliable analyses of certain typical occurrences.

931



932



Wellsite. $RAl_2Si_3O_{10}.3H_2O$ with R = Ca : Ba : K_2 = 3 : 1 : 3; Sr and Na also present in small amount. Percentage composition: SiO_2 42·9, Al_2O_3 24·3, BaO 6·6, CaO 7·3, K_2O 6·1, H_2O 12·8 = 100. Monoclinic (axes above); in complex twins, analogous to those of phillipsite and harmotome (Figs. 931, 932). Brittle. No cleavage. H. = 4–4·5. G. = 2·278–2·366. Luster vitreous. Colorless to white. Optically +. Bx ⊥ *b* (010). Birefringence weak.

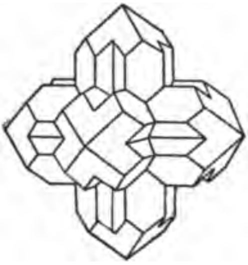
Occurs at the Buck Creek (Cullakanee) corundum mine in Clay Co., N. C.; in isolated crystals attached to feldspar, also to hornblende and corundum; intimately associated with chabazite. Also found at Kurzy near Simferopol, Crimea, Russia.

PHILLIPSITE.

Monoclinic. Axes $a : b : c = 0{\cdot}7095 : 1 : 1{\cdot}2563$; $\beta = 55° 37'$.

mm''', $110 \wedge 1\bar{1}0 = 60° 42'$. *cm*, $001 \wedge 110 = 60° 50'$.
af, $100 \wedge \bar{1}01 = 34° 23'$. *ee'*, $011 \wedge 0\bar{1}1 = 92° \ 4'$.

933



Crystals uniformly penetration-twins, but often simulating orthorhombic or tetragonal forms. Twins sometimes, but rarely, simple (1) with tw. pl. *c* (001), and then cruciform so that diagonal parts on *b* (010) belong together, hence a fourfold striation, || edge *b*/*m*, may be often observed on *b*. (2) Double twins, the simple twins just noted united with *e* (011) as tw. pl., and, since *ee'* varies but little from 90°, the result is a nearly square prism, terminated by what appear to be pyramidal faces each with a double series of striations away from the medial line. See Figs. 452–454, p. 172; also Fig. 400, p. 164. Faces *b* (010) often finely striated as just noted, but striations sometimes absent and in general not so distinct as with harmotome; also *m* (110) striated || edge *b*/*m*. Crystals either isolated, or grouped in tufts or spheres, radiated within and bristled with angles at surface.

Cleavage: *c* (001), *b* (010), rather distinct. Fracture uneven. Brittle. H. = 4–4·5. G. = 2·2. Luster vitreous. Color white, sometimes reddish. Streak uncolored. Translucent to opaque. Optically +. Ax. pl. and Bx_o ⊥ *b* (010). The ax. pl. lies in the obtuse angle of the *a*–*c* axes, and is usually inclined to *a* axis about 15° to 20°, or 75° to 70° to the normal to *c* (001). The position, however, is variable. $2H_{a.r} = 71°–84°$. Indices, 1·48–1·57.

Comp. — In some cases the formula is $(K_2,Ca)Al_2Si_4O_{12}.4H_2O$ = Silica 48·8, alumina 20·7, lime 7·6, potash 6·4, water 16·5 = 100. Here Ca : K_2 = 2 : 1.

Pyr., etc. — B.B. crumbles and fuses at 3 to a white enamel. Gelatinizes with hydrochloric acid.

Obs. — In translucent crystals in basalt, at the Giant's Causeway, Ireland; at Capo di Bove, near Rome; Aci Castello and elsewhere in Sicily; among the lavas of Mte. Somma, Vesuvius; in Germany at Stempel, near Marburg; Annerod, near Giessen; in the Kaiserstuhl, with faujasite, at Salesl, Bohemia; in the ancient lavas of the Puy-de-Dôme, France; from Richmond, Victoria. *Pseudophillipsite*, found near Rome, Italy, differs from phillipsite only in the manner in which it loses water on heating.

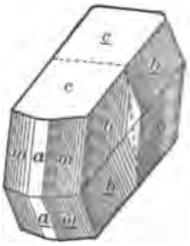
HARMOTOME.

Monoclinic. Axes $a : b : c = 0{\cdot}7031 : 1 : 1{\cdot}2310$; $\beta = 55° 10'$.

Crystals uniformly cruciform penetration-twins with *c* (001) as tw. pl.; either (1) simple twins (Fig. 934) or (2) united as fourlings with tw. pl. *e* (011). These double twins often have the aspect of a square prism with diagonal pyramid, the latter with characteristic feather-like striations from the medial line. Also in more complex groups analogous to those of phillipsite.

Cleavage: *b* (010) easy, *c* (001) less so. Fracture uneven to subconchoidal. Brittle. H. = 4·5. G. = 2·44–2·50. Luster vitreous. Color white; passing into gray, yellow, red or brown. Streak white. Subtransparent to translucent.

934



Ax. pl. and $\mathrm{Bx_a}$ ⊥ *b* (010). Ax. pl. in obtuse angle *a–c* axes and inclined about 65° to *a* axis and 60° to *c* axis. Optically +. 2V = 43°. $\alpha = 1{\cdot}503$. $\beta = 1{\cdot}505$. $\gamma = 1{\cdot}508$.

Comp. — In part $H_2(K_2,Ba)Al_2Si_5O_{15}.4H_2O$ or $(K_2,Ba)O.Al_2O_3.5SiO_2.5H_2O$ = Silica 47·1, alumina 16·0, baryta 20·6, potash 2·1, water 14·1 = 100.

Pyr., etc. — B.B. whitens, then crumbles and fuses without intumescence at 3·5 to a white translucent glass. Some varieties phosphoresce when heated. Decomposed by hydrochloric acid without gelatinizing.

Obs. — Occurs in basalt and similar eruptive rocks, also phonolite, trachyte; not infrequently on gneiss, and in some metalliferous veins. At Strontian, in Scotland; in a metalliferous vein at Andreasberg in the Harz Mts., Germany; at Rudelstadt, Silesia; Oberstein, Germany, on agate in siliceous geodes; at Kongsberg, Norway.

In the United States, in small brown crystals with stilbite on the gneiss of New York Island; near Port Arthur, Lake Superior.

Named from ἁρμός, *joint*, and τέμνειν, *to cut*, alluding to the fact that the pyramid (made by the prismatic faces in twinning position) divides parallel to the plane that passes through the terminal edges.

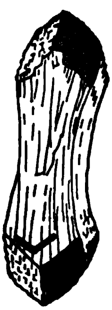
STILBITE. Desmine.

Monoclinic. Axes *a* : *b* : *c* = 0·7623 : 1 : 1·1940; β = 50° 50′.

Crystals uniformly cruciform penetration-twins with tw. pl. *c* (001), analogous to phillipsite and harmotome. The apparent form a rhombic pyramid whose faces are in fact formed by the prism faces of the two individuals; the vertical faces being then the pinacoids *b* (010) and *c* (001) (cf. Figs. 613–615, p. 299). Usually thin tabular || *b* (010). These compound crystals are often grouped in nearly parallel position, forming sheaf-like aggregates with the side face (*b*), showing its characteristic pearly luster, often deeply depressed. Also divergent or radiated; sometimes globular and thin lamellar-columnar.

Cleavage: *b* (010) perfect. Fracture uneven. Brittle. H. = 3·5–4. G. = 2·094–2·205. Luster vitreous; of *b* (010) pearly. Color white; occasionally yellow, brown or red, to brick-red. Streak uncolored. Transparent to translucent. Optically −. Ax. pl. || *b* (010). $\mathrm{Bx_a}$ inclined 5° to axis *a* in obtuse angle *a–c* axes; hence $\mathrm{Bx_a} \wedge c$ axis = − 55° 50′. 2V = 33° (approx.). $\alpha = 1{\cdot}494$. $\beta = 1{\cdot}498$. $\gamma = 1{\cdot}500$.

935



Comp. — For most varieties $H_4(Na_2,Ca)Al_2Si_6O_{18}.4H_2O$ or $(Na_2,Ca)O.Al_2O_3.6SiO_2.6H_2O$ = Silica 57·4, alumina 16·3, lime 7·7, soda 1·4, water 17·2 = 100. Here Ca : Na_2 = 6 : 1.

Some kinds show a lower percentage of silica, and these have been called *hypostilbite*.

Pyr., etc. — B.B. exfoliates, swells up, curves into fan-like or vermicular forms, and fuses to a white enamel. F. = 2–2·5. Decomposed by hydrochloric acid, without gelatinizing.

Diff. — Characterized by the frequency of radiating or sheaf-like forms; by the pearly luster on the clinopinacoid. Does not gelatinize with acids.

Obs. — Stilbite occurs mostly in cavities in amygdaloidal basalt, and similar rocks. It is also found in some metalliferous veins, and in granite and gneiss.

Abundant on the Faroe Islands; in Iceland; on the Isle of Skye, in amygdaloid; also in Dumbartonshire, Scotland, in red crystals; the Giant's Causeway, Ireland; at Andreasberg in the Harz Mts., Germany, and Kongsberg and Arendal in Norway, with iron ore; on the Seisser Alp in Tyrol, Austria, and at the Pufierloch (*puflerite*); on the granite of Striegau, Silesia. A common mineral in the Deccan trap area of British India.

In North America, sparingly in small crystals at Chester and at the Somerville syenite quarries, Mass.; at Phillipstown, N. Y.; and at Bergen Hill, West Paterson and Great Notch, N. J.; also at the Michipicoten Islands, Lake Superior. In Nova Scotia at Partridge Island, also at Isle Haute, Two Islands, Digby Neck, Cape Blomidon, etc.

The name *stilbite* is from στίλβη, *luster*, and *desmine* from δέσμη, *a bundle*.

Flokite. $H_8(Ca,Na_2)Al_2Si_9O_{26}.2H_2O$. Monoclinic. In slender prismatic crystals. Perfect cleavages parallel to (100) and (010). H. = 5. G. = 2·10. Colorless and transparent. Indices, 1·472–1·474. Fuses with intumescence. From Iceland.

Gismondite. Perhaps $CaAl_2Si_2O_8.4H_2O$. In pyramidal crystals, pseudo-tetragonal. H. = 4·5. G. = 2·265. Colorless or white, bluish white, grayish, reddish. Biaxial, –. Index, 1·539. Occurs in the leucitophyre of Mt. Albano, near Rome, at Capo di Bove, and elsewhere, etc.; on the Gorner glacier, near Zermatt, Switzerland; Schlauroth near Görlitz in Silesia; Salesl, Bohemia, etc.

LAUMONTITE. Leonhardite. Caporcianite.

Monoclinic. Axes $a : b : c = 1·1451 : 1 : 0·5906$; $\beta = 68° 46'$.

Twins: tw. pl. *a* (100). Common form the prism *m* (mm''' 110 ∧ $1\bar{1}0$ = 93° 44′) with oblique termination *e*, $\bar{2}01$ (*ce* 001 ∧ $\bar{2}01$ = 56° 55′). Also columnar, radiating and divergent.

Cleavage: *b* (010) and *m* (110) very perfect; *a* (100) imperfect. Fracture uneven. Not very brittle. H. = 3·5–4. G. = 2·25–2·36. Luster vitreous, inclining to pearly upon the faces of cleavage. Color white, passing into yellow or gray, sometimes red. Streak uncolored. Transparent to translucent; becoming opaque and usually pulverulent on exposure. Optically –. Ax. pl. ∥ *b* (010). $Bx_a \wedge c$ axis = + 65° to 70°. Dispersion large, $\rho < v$; inclined, slight. $2E_r = 52° 24'$. $\alpha = 1·513$. $\beta = 1·524$. $\gamma = 1·525$.

Comp. — $H_4CaAl_2Si_4O_{14}.2H_2O = 4H_2O.CaO.Al_2O_3.4SiO_2$ = Silica 51·1, alumina 21·7, lime 11·9, water 15·3 = 100.

Var. — *Leonhardite* is a laumontite which has lost part of its water (to one molecule), and the same is probably true of *caporcianite*. *Schneiderite* is laumontite from the serpentine of Monte Catini, Italy, which has undergone alteration through the action of magnesian solutions.

Pyr., etc. — B.B. swells up and fuses at 2·5–3 to a white enamel. Gelatinizes with hydrochloric acid.

Obs. — Occurs in the cavities of basalt and similar eruptive rocks; also in porphyry and syenite, and occasionally in veins traversing clay slate with calcite.

Its principal localities are the Faroe Islands; Disko in Greenland; in Bohemia, at Eule in clay slate; St. Gothard in Switzerland; Baveno, Italy; Nagyag, Transylvania; the Fassatal, Tyrol, Austria; the Kilpatrick hills, near Glasgow, Scotland; the Hebrides, and the north of Ireland. In India, in the Deccan trap area, at Poona, etc.

Peter's Point, Nova Scotia, affords fine specimens of this species. Found at Phippsburg, Me. Abundant in many places in the copper veins of Lake Superior in trap, and on Isle Royale; on north shore of Lake Superior, between Pigeon Bay and Fond du Lac. Found also at Bergen Hill, N. J.; at the Tilly Foster iron mine, Brewster, N. Y.

Laubanite. $Ca_2Al_2Si_5O_{15}.6H_2O$. Resembles stilbite. H. = 4·5–5. G. = 2·23. Color snow-white. Occurs upon phillipsite in basalt at Lauban, Silesia.

Chabazite Group. Rhombohedral

		rr'	c
Chabazite	$(Ca,Na_2)Al_2Si_4O_{12}.6H_2O$	85° 14′	1·0860
Gmelinite	$(Na_2Ca)Al_2Si_4O_{12}.6H_2O$	68° 8′	0·7345 or $\frac{3}{2}c$ = 1·1017
Levynite	$CaAl_2Si_3O_{10}.5H_2O$	73° 56′	0·8357 $\frac{4}{3}c$ = 1·1143

The Chabazite Group includes these three rhombohedral species. The fundamental rhombohedrons have different angles, but, as shown in the axial ratios above, they are closely related, since, taking the rhombohedron of Chabazite as the basis, that of Gmelinite has the symbol ($20\bar{2}3$) and of Levynite ($30\bar{3}4$).

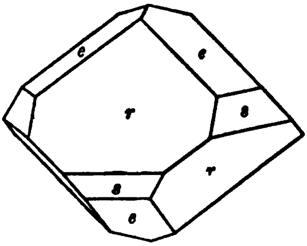
The variation in composition often observed in the first two species has led to the rather plausible hypothesis that they are to be viewed as isomorphous mixtures of the feldspar-like compounds

$(Ca,Na_2)Al_2Si_2O_8.4H_2O$, $(Ca,Na_2)Al_2Si_6O_{16}.8H_2O$.

CHABAZITE.

Rhombohedral. Axis c = 1·0860; 0001 ∧ 1011 = 51° 25¾′.

936



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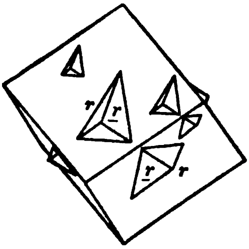

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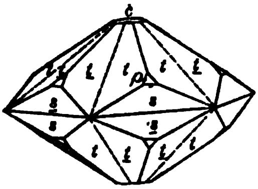


Phacolite

Twins: (1) tw. axis c axis, penetration-twins common. (2) Tw. pl. r (10$\bar{1}$1); contact-twins, rare. Form commonly the simple rhombohedron varying little in angle from a cube (rr' 1$\bar{1}$01 ∧ $\bar{1}$101 = 85° 14′); also r and e (01$\bar{1}$2), (ee' = 54° 47′). Also in complex twins. Also amorphous.

Cleavage: r (10$\bar{1}$1) rather distinct. Fracture uneven. Brittle. H. = 4–5. G. = 2·08–2·16. Luster vitreous. Color white, flesh-red; streak uncolored. Transparent to translucent. Optically −; also + (Andreasberg, also *haydenite*). Birefringence low. The interference-figure usually confused; sometimes distinctly biaxial; basal sections then divided into sharply defined sectors with different optical orientation. These anomalous optical characters probably secondary and chiefly conditioned by the variation in the amount of water present. Mean refractive index 1·5.

Var. — 1. *Ordinary.* The most common form is the fundamental rhombohedron, in which the angle is so near 90° that the crystals were at first mistaken for cubes. *Acadialite,* from Nova Scotia (*Acadia* of the French of 18th century), is a reddish chabazite; sometimes nearly colorless. *Haydenite* is a yellowish variety in small crystals from Jones's Falls, near Baltimore, Md. 2. *Phacolite* is a colorless variety occurring in twins of hexagonal form (Fig. 938), and lenticular in shape (whence the name, from *φακός, a bean*); the original was from Leipa in Bohemia. Here belongs also *herschelite* (seebachite) from Richmond, Victoria; the composite twins of great variety and beauty. Probably also the original herschelite from Sicily. It occurs in flat, almost tabular, hexagonal prisms with rounded terminations divided into six sectors.

Comp. — Somewhat uncertain, since a rather wide variation is often noted even among specimens from the same locality. The ratio of (Ca,Na_2,K_2) : Al is nearly constant (= 1 : 1), but of Al_2 : Si varies from 1 : 3 to 1 : 5; the water also increases with the increase in silica. The composition usually corresponds to $(Ca,Na_2)Al_2Si_4O_{12}.6H_2O$, which, if calcium alone is present, requires: Silica 47·4, alumina 20·2, lime 11·1, water 21·3 = 100. If Ca : Na_2 = 1 : 1, the percentage composition is: Silica 47·2, alumina 20·0, lime 5·5, soda 6·1, water 21·2 = 100.

Potassium is present in small amount, also sometimes, barium and strontium. Streng explains the supposed facts most satisfactorily by the hypothesis that the members of the group are isomorphous mixtures analogous to the feldspars, as noted above.

Pyr., etc. — B.B. intumesces and fuses to a blebby glass, nearly opaque. Decomposed by hydrochloric acid, with separation of slimy silica.

Diff. — Characterized by rhombohedral form (resembling a cube). It is harder than calcite and does not effervesce with acid; unlike calcite and fluorite in cleavage; fuses B.B. with intumescence unlike analcite.

Obs. — Occurs mostly in basaltic rocks, and occasionally in gneiss, syenite, mica schist, hornblendic schist. Occurs at the Faroe Islands, Greenland, and Iceland, associated with chlorite and stilbite; at Aussig in Bohemia; in Germany at Oberstein, with harmotome, and at Annerod, near Giessen; at the Giant's Causeway, Antrim, Ireland, and Renfrewshire, Scotland; Isle of Skye, etc. In Australia (*phacolite*) at Richmond, near Melbourne, etc.

In the United States, in syenite at Somerville, Mass.; at Bergen Hill and West Paterson, N. J., in crystals; at Jones's Falls near Baltimore, Md. (*haydenite*). In Nova Scotia, wine yellow or flesh-red (the last the *acadialite*), associated with heulandite, analcite and calcite, at Five Islands, Swan's Creek, Digby Neck, Two Islands, Wasson's Bluff, etc.

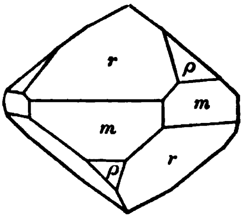
The name *chabazite* is from χαβάζιος, an ancient name of a stone.

GMELINITE.

Rhombohedral. Axis $c = 0{\cdot}7345$.

Crystals usually hexagonal in aspect; sometimes ρ $(01\bar{1}1)$ smaller than $r(10\bar{1}1)$, and habit rhombohedral; rr' $10\bar{1}1 \wedge \bar{1}101 = 68° 8'$, $r\rho$ $10\bar{1}1 \wedge 01\bar{1}1 = 37° 44'$.

939



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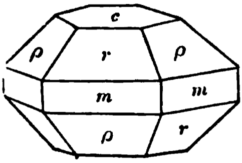


Cleavage: m $(10\bar{1}0)$ easy; $c\,(0001)$ sometimes distinct. Fracture uneven. Brittle. H. = 4·5. G. = 2·04–2·17. Luster vitreous. Colorless, yellowish white, greenish white, reddish white, flesh-red. Transparent to translucent. Optically positive, also negative. Birefringence very low. Interference-figure often disturbed, and basal sections divided optically into sections analogous to chabazite. Mean refractive index, 1·47.

Comp. — In part $(Na_2,Ca)Al_2Si_4O_{12}.6H_2O$. If sodium alone is present this requires: Silica 46·9, alumina 19·9, soda 12·1, water 21·1 = 100. See also p. 552.

Pyr., etc. — B.B. fuses easily (F. = 2·5–3) to a white enamel. Decomposed by hydrochloric acid with separation of silica.

Obs. — Occurs in flesh-red crystals in amygdaloidal rocks at Montecchio Maggiore, Italy; at Andreasberg, Germany; in Transylvania; Antrim, Ireland; Talisker in Isle of Skye, in large colorless crystals. In Australia at Flinders, Victoria.

In the United States in fine white crystals at Bergen Hill, Great Notch and Paterson, N. J. At Cape Blomidon, Nova Scotia (*ledererite*); also at Two Islands and Five Islands.

Named *Gmelinite* after Prof. Gmelin of Tübingen (1792–1860).

Levynite. $CaAl_2Si_3O_{10}.5H_2O$. In rhombohedral crystals. H. = 4–4·5. G. = 2·09–2·16. Colorless, white, grayish, reddish, yellowish. Optically −. $\omega = 1{\cdot}50$. Found at Glenarm and at Island Magee, Antrim, Ireland; at Dalsnypen, Faroe Islands, in Iceland; in East Greenland; in the basalt of Table Mountain near Golden, Col.

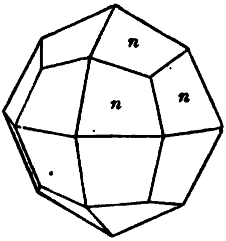
Offretite. A potash zeolite, related to the species of the chabazite group. In basalt of Mont Simiouse, France.

ANALCITE. Analcime.

Isometric. Usually in trapezohedrons; also cubes with faces n (211); again the cubic faces replaced by a vicinal trisoctahedron. Sometimes in composite groups about a single crystal as nucleus (Fig. 389, p. 161). Also massive granular; compact with concentric structure.

Cleavage: cubic, in traces. Fracture subconchoidal. Brittle. H. = 5–5·5. G. = 2·22–2·29. Luster vitreous. Colorless, white; occasionally grayish, greenish, yellowish, or reddish white. Transparent to nearly opaque. Often shows weak double refraction, which is apparently connected with loss of water and consequent change in molecular structure (Art. 429). $n = 1{\cdot}4874$.

941



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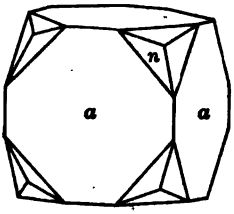


Comp. — $NaAlSi_2O_6H_2O$ = $Na_2O.Al_2O_3.4SiO_2.2H_2O$ = Silica 54.5, alumina 23·2, soda 14·1, water 8·2 = 100.

Analyses show always a varying excess of silica and water above amounts required by formula. It has been assumed that a molecule containing the acid $H_2Si_2O_5$ is present in soild solution in small amounts.

Pyr., etc. — Yields water in the closed tube. B.B. fuses at 2·5 to a colorless glass. Gelatinizes with hydrochloric acid.

Diff. — Characterized by trapezohedral form, but is softer than garnet, and yields water B.B., unlike leucite (which is also infusible); fuses without intumescence to a clear glass unlike chabazite. From leucite and sodalite surely distinguished only by chemical tests, i.e., absence of chlorine in the nitric-acid test (see sodalite, p. 502), absence of much potash and abundance of soda in the solution, and evolution of much water from the powder in a closed glass tube below a red heat.

Micro. — Recognized in thin sections by its very low relief and isotropic character; often shows optical anomalies.

Obs. — Occurs frequently with other zeolites, also prehnite, calcite, etc., in cavities and seams in basic igneous rocks, as basalt, diabase, etc.; also in granite, gneiss, etc. Recently shown to be also a rather widespread component of the groundmass of various basic igneous rocks, at times being the only alkali-alumina silicate present, as in the so-called analcite-basalts. Has been held in such cases to be a primary mineral produced by the crystallization of a magma containing considerable soda and water vapor held under pressure.

The Cyclopean Islands, near Catania, Sicily, afford pellucid crystals; also the Fassatal in Tyrol, Austria; other localities are, in Scotland, in the Kilpatrick Hills; Co. Antrim, etc., in Ireland; the Faroe Islands; Iceland; near Aussig, Bohemia; at Arendal, Norway, in beds of iron ore; at Andreasberg, in the Harz Mts., Germany, in silver mines.

In the United States, occurs at Bergen Hill and West Paterson, N. J.; in gneiss near Yonkers, Westchester Co., N. Y.; abundant in fine crystals with prehnite, datolite, and calcite, in the Lake Superior region; at Table Mt. near Golden, Col., with other zeolites. Nova Scotia affords fine specimens.

The name *analcime* is from ἀναλκις, *weak*, and alludes to its weak electric power when heated or rubbed. The correct derivative is *analcite*, as here adopted for the species.

Faujasite. Perhaps $H_4Na_2CaAl_4Si_{10}O_{28}.18H_2O$.

In isometric octahedrons. H. = 5. G. = 1·923. Colorless, white. $n = 1{\cdot}48$. Occurs with augite in the limburgite of Sasbach in the Kaiserstuhl, Baden, Germany, etc.

Edingtonite. Perhaps $BaAl_2Si_3O_{10}.3H_2O$. Crystals pyramidal in habit (orthorhombic, pseudo-tetragonal); also massive. H. = 4–4·5. G. = 2·694. White, grayish white, pink. Optically −. Indices, 1·538–1·554. Occurs in the Kilpatrick Hills, near Glasgow, Scotland, with harmotome. From Böhlet, Sweden.

Natrolite Group. Orthorhombic and Monoclinic

		a : b : c	β
Natrolite	$Na_2Al_2Si_3O_{10}.2H_2O$	0·9785 : 1 : 0·3536	
		a : b : c	β
Scolecite	$Ca(AlOH)_2(SiO_3)_3.2H_2O$	0·9764 : 1 : 0·3434	89° 18′
Mesolite	$\begin{cases} Na_2Al_2Si_3O_{10}.2H_2O \\ 2[CaAl_2Si_3O_{10}.3H_2O] \end{cases}$		

The three species of the NATROLITE GROUP agree closely in angle, though varying in crystalline system; Natrolite is orthorhombic usually, also rarely monoclinic; Scolecite is monoclinic, perhaps also in part triclinic; Mesolite seems to be both monoclinic and triclinic. Fibrous, radiating or divergent groups are common to all these species.

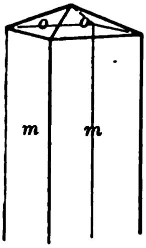
The Natrolite Group includes the sodium silicate, Natrolite, with the empirical formula $Na_2Al_2Si_3O_{10}.2H_2O$; the calcium silicate, Scolecite, $CaAl_2Si_3O_{10}.3H_2O$; also Mesolite intermediate between these and corresponding to $\left\{\begin{array}{l} mNa_2Al_2Si_3O_{10}.2H_2O \\ nCaAl_2Si_3O_{10}.3H_2O. \end{array}\right.$

NATROLITE.

Orthorhombic.[*] Axes $a : b : c = 0·9785 : 1 : 0·3536$.

mm''', $110 \wedge 1\bar{1}0 = 88° 45\frac{1}{2}'$.
mo, $110 \wedge 111 = 63° 11'$.
oo', $111 \wedge \bar{1}11 = 37° 38'$.
oo''', $111 \wedge 1\bar{1}1 = 36° 47\frac{1}{2}'$.

943



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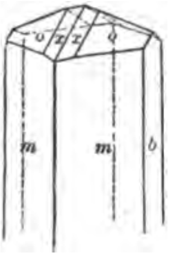

Crystals prismatic, usually very slender to acicular; frequently divergent, or in stellate groups. Also fibrous, radiating, massive, granular, or compact.

Cleavage: *m* (110) perfect; *b* (010) imperfect, perhaps only a plane of parting. Fracture uneven. H. = 5–5·5. G. = 2·20–2·25. Luster vitreous, sometimes inclining to pearly, especially in fibrous varieties. Color white, or colorless; to grayish, yellowish, reddish to red. Transparent to translucent. Optically +. Ax. pl. *b* (010). Bx $\perp$ *c* (001). $2V = 63°$. $\alpha = 1·480$. $\beta = 1·482$. $\gamma = 1·493$.

Var. — *Ordinary*. Commonly either (*a*) in groups of slender colorless prismatic crystals, varying but little in angle from square prisms, often acicular, or (*b*) in fibrous divergent or radiated masses, vitreous in luster, or but slightly pearly (these radiated forms often resemble those of thomsonite and pectolite); often also (*c*) solid amygdules, usually radiated fibrous, and somewhat silky in luster within; (*d*) rarely compact massive. *Galactite* is ordinarily natrolite, in colorless needles from southern Scotland.

Bergmannite, spreustein, brevicite, are names which have been given to the natrolite from the augite-syenite of southern Norway, on the Langesund fiord, in the "Brevik" region, where it occurs fibrous, massive, and in long prismatic crystallizations, and from white to red in color. Derived in part from elæolite, in part from sodalite. *Iron-natrolite* is a dark green opaque variety, either crystalline or amorphous, from the Brevik region; the iron is due to inclusions.

Comp. — $Na_2Al_2Si_3O_{10}.2H_2O$ or $Na_2O.Al_2O_3.3SiO_2.2H_2O$ = Silica 47·4, alumina 26·8, Na_2O 16·3, water 9·5 = 100.

Pyr., etc. — In the closed tube whitens and becomes opaque. B.B. fuses quietly at 2 to a colorless glass. Fusible in the flame of an ordinary wax candle. Gelatinizes with acids.

Diff. — Distinguished from aragonite and pectolite by its easy fusibility and gelatinization with acid.

Obs. — Occurs in cavities in amygdaloidal basalt, and other related igneous rocks; sometimes in seams in granite, gneiss, and syenite. Found at Aussig and Teplitz in Bohemia; in fine crystals in Auvergne, France; Fassatal, Tyrol, Austria; Kapnik, Hungary. In red amygdules (*crocalite*) in amygdaloid of Ireland, Scotland and Tyrol; the amygdaloid of Bishopton, Scotland (*galactite*) and at Glen Farg (*fargite*) in Fifeshire. Common in the augite-syenite of the Langesund fiord, near Brevik, southern Norway. From various localities in Greenland.

In North America, in the trap of Nova Scotia; at Bergen Hill and West Paterson, N. J.; at Copper Falls, Lake Superior; from benitoite locality, San Benito Co., Cal.

Named *Mesotype* by Haüy, from *μέσος, middle*, and *τύπος, type*, because the form of the crystal — in his view a square prism — was intermediate between the forms of stilbite and analcite. *Natrolite*, of Klaproth, is from *natron, soda;* it alludes to the presence of soda, whence also the name *soda-mesotype*, in contrast with scolecite, or *lime-mesotype*.

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[*] In rare cases the crystals seem to be monoclinic.

SCOLECITE.

Monoclinic. Axes $a : b : c = 0{\cdot}9764 : 1 : 0{\cdot}3434$; $\beta = 89° \, 18'$.

Crystals slender prismatic (mm''' $110 \wedge 1\bar{1}0 = 88° \, 37\tfrac{1}{2}'$), twins showing a feather-like striation on b (010), diverging upward; also as penetration-twins. Crystals in divergent groups. Also massive, fibrous and radiated, and in nodules.

Cleavage: m (110) nearly perfect. H. = 5–5·5. G. = 2·16–2·4. Luster vitreous, or silky when fibrous. Transparent to subtranslucent. Optically −. Ax. pl. and $Bx_o \perp b$ (010). $Bx_a \wedge c$ axis = 15°–16°. 2V = 36° (approx.). $\alpha = 1{\cdot}512$. $\beta = 1{\cdot}519$. $\gamma = 1{\cdot}519$.

Comp. — $CaAl_2Si_3O_{10}.3H_2O$ or $CaO.Al_2O_3.3SiO_2.3H_2O$ = Silica 45·9, alumina 26·0, lime 14·3, water 13·8 = 100.

Pyr., etc. — B.B. sometimes curls up like a worm (whence the name from σκώληξ, *a worm*, which gives *scolecite*, and not *scolesite* or *scolezite*); other varieties intumesce but slightly, and all fuse at 2–2·2 to a white blebby enamel. Gelatinizes with acids like natrolite.

Obs. — Occurs in the Berufiord, Iceland; in Scotland in amygdaloid at Staffa Island and in Isle of Skye, at Talisker; near Eisenach, Saxony; in Auvergne, France; common in fine crystallizations in the Deccan trap area, in British India. In crystals from Karsanan-guit-Kakait, Greenland. In the United States, in Col. at Table Mountain near Golden in cavities in basalt. In Canada, at Black Lake, Megantic Co., Quebec.

Mesolite. Intermediate between natrolite and scolecite (see p. 556). In acicular and capillary crystals; delicate divergent tufts, etc. G. = 2·29. White or colorless. Indices, 1·505–1·506. In amygdaloidal basalt at numerous points. Crystals from Faroe Islands appear to be triclinic, pseudomonoclinic through twinning. *Pseudomesolite* is name given to a zeolite from Carlton Peak, Minn., like mesolite except for its optical characters.

Gonnardite. $(Ca,Na_2)_2Al_2Si_5O_{15}.5\tfrac{1}{2}H_2O$. In spherules with radiating structure. G. = 2·25–2·35. From basalt of Gignat, Puy-de-Dôme, France.

THOMSONITE.

Orthorhombic. Axes $a : b : c = 0{\cdot}9932 : 1 : 1{\cdot}0066$.

Distinct crystals rare; in prisms, mm''' $110 \wedge 1\bar{1}0 = 89° \, 37'$. Commonly columnar, structure radiated; in radiated spherical concretions; also closely compact.

Cleavage: b (010) perfect; a (100) less so; c (001) in traces. Fracture uneven to subconchoidal. Brittle. H. = 5–5·5. G. = 2·3–2·4. Luster vitreous, more or less pearly. Snow-white; reddish, green; impure varieties brown. Streak uncolored. Transparent to translucent. Pyroelectric. Optically +. Ax. pl. $\parallel c$ (001). $Bx \perp b$ (010). Dispersion $\rho > v$ strong. 2V = 54° (approx.). $\alpha = 1{\cdot}497$. $\beta = 1{\cdot}503$. $\gamma = 1{\cdot}525$.

Var. — 1. *Ordinary.* (*a*) In regular crystals, usually more or less rectangular in outline, prismatic in habit. (*b*) Prisms slender, often vesicular to radiated. (*c*) Radiated fibrous. (*d*) Spherical concretions, consisting of radiated fibers or slender crystals. Also massive, granular to impalpable, and white to reddish brown, less often green as in *lintonite*. The spherical massive forms also radiated with several centers and of varying colors, hence of much beauty when polished. *Ozarkite* is a white massive thomsonite from Arkansas.

Comp. — $(Na_2,Ca)Al_2Si_2O_8.2\tfrac{1}{2}H_2O$ or $(Na_2,Ca)O.Al_2O_3.2SiO_2.2\tfrac{1}{2}H_2O$. The ratio of $Na_2 : Ca$ varies from 3 : 1 to 1 : 1. If $Ca : Na_2 = 3 : 1$ the percentage composition requires: SiO_2 37·0, Al_2O_3 31·4, CaO 12·9, Na_2O 4·8, H_2O 13·9 = 100.

Pyr., etc. — B.B. fuses with intumescence at 2 to a white enamel. Gelatinizes with hydrochloric acid.

Diff. — Resembles some natrolite, but fuses to an opaque, not to a clear glass.

Obs. — Found in cavities in lava in amygdaloidal igneous rocks, sometimes with elæolite as a result of its alteration. Occurs near Kilpatrick, Scotland; in the lavas of Mte Somma (*comptonite*), Vesuvius; in basalt at the Pflasterkaute in Saxe Weimar, Germany; in Bohemia, in phonolite; the Cyclopean islands, Sicily; near Brevik, Norway; the Faroe Islands; Iceland (carphostilbite, straw-yellow); at Mt. Monzoni, Fassatal, Tyrol, Austria.

Occurs at Peter's Point, Nova Scotia. In the United States, at West Paterson, N. J. at Magnet Cove (*ozarkite*) in the Ozark Mts., Ark.; in the amygdaloid of Grand Marais, Lake Superior, which yields the water-worn pebbles resembling agate, in part green (*lintonite*); in the basalt of Table Mt. near Golden, Col.

HYDROTHOMSONITE. $(H_2,Na_2,Ca)Al_2Si_2O_8.5H_2O$. An alteration product of thomsonite or scolecite from Tschakwa near Batum on the Black Sea.

Arduinite. A zeolite containing lime and soda. In radiating fibrous aggregates. G. = 2·26. Color red. From Val dei Zuccanti, Venetia, Italy.

Echellite. $(Ca,Na_2)O.2Al_2O_3.3SiO_2\ 4H_2O$. In radiating, fibrous, spheroidal masses. White. H. = 5. $\beta = 1{\cdot}533$. Elongated ‖ Y. From Sextant Portage, Abitibi River, Northern Ontario.

Epidesmine. Comp. same as for stilbite. Orthorhombic. In minute crystals, only the three pinacoids showing. Cleavages parallel to both vertical pinacoids. Colorless to yellow. Index = 1·50. Bx$_a$ perpendicular to *c* (001). Optically −. G. = 2·16. Easily fusible with intumescence. Occurs as a crust on calcite from Schwarzenberg, Saxony.

Stellerite. $CaAl_2Si_7O_{18}.7H_2O$. Orthorhombic. Crystals tabular parallel to *b* (010). Cleavage perfect parallel to *b* (010), imperfect parallel to *a* (100) and *c* (001). H. = 3·5–4. G. = 2·12. Indices, 1·48–1·50. Found in cavity in a diabase tuff, Copper Island, Commander Islands.

Erionite. $H_2CaK_2Na_2Al_2Si_6O_{17}.5H_2O$. Orthorhombic. In aggregates of very slender fibers, resembling wool. G. = 1·997. White. Occurs in cavities in rhyolite from Durkee, Oregon.

Bavenite. $Ca_3Al_2(SiO_3)_6.H_2O$. Monoclinic. Fibrous-radiated groups of prismatic crystals. One cleavage. H. = 5·5. G. = 2·7. Color white. $\beta = 1{\cdot}58$. Occurs in pegmatitic druses in the granite of Baveno, Italy.

Bityite. A hydrous silicate of calcium and aluminium, with small amounts of the alkalies. Pseudo-hexagonal. In minute hexagonal plates which in polarized light show division into six biaxial sectors. Cleavage parallel to base. H. = 5·5. G. = 3·0. Indices 1·62–1·64. Found as crystal crusts in pegmatite veins at Maharitra, Madagascar.

Hydronephelite. $HNa_2Al_3Si_3O_{12}.3H_2O$. Massive, radiated. H. = 4·5–6. G. = 2·263. Color white; also dark gray. Index, 1·50. From Litchfield, Me.; said however to be a mixture of natrolite, hydrargillite and diaspore. *Ranite* from the Langesund fiord, Norway, is similar.

II. Mica Division

The species embraced under this Division fall into three groups: 1, the MICA GROUP, including the Micas proper; 2, the CLINTONITE GROUP, or the Brittle Micas; 3, the CHLORITE GROUP. Supplementary to these are the Vermiculites, hydrated compounds, chiefly results of the alteration of some one of the micas.

All of the above species have the characteristic micaceous structure, that is, they have highly perfect basal cleavage and yield easily thin laminæ. They belong to the monoclinic system, but the position of the bisectrix in general deviates but little from the normal to the plane of cleavage; all of them show on the basal section plane angles of 60° or 120°, marking the relative position of the chief zones of forms present, and giving them the appearance of hexagonal or rhombohedral symmetry; further, they are more or less closely related among themselves in the angles of prominent forms.

The species of this Division all yield water upon ignition, the micas mostly from 4 to 5 p. c., the chlorites from 10 to 13 p. c.; this is probably to be regarded in all cases as water of constitution, and hence they are not properly *hydrous* silicates.

More or less closely related to these species are those of the Serpentine and Talc Division and the Kaolin Division following, many of which show distinctly a mica-like structure and cleavage and also pseudo-hexagonal symmetry.

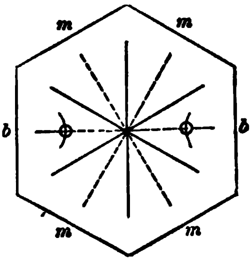
1. *Mica Group.* Monoclinic

Muscovite	Potassium Mica	$H_2KAl_3(SiO_4)_3$	
		$a : b : c = 0{\cdot}57735 : 1 : 3{\cdot}3128$	$\beta = 89° 54'$
Paragonite	Sodium Mica	$H_2NaAl_3(SiO_4)_3$	
Lepidolite	Lithium Mica	$KLi[Al(OH,F)_2]Al(SiO_3)_3$ in part.	
Zinnwaldite	Lithium-iron Mica		
Biotite	Magnesium-iron Mica	$(H,K)_2(Mg,\overset{II}{Fe})_2(Al,\overset{III}{Fe})_2(SiO_4)_3$ in part.	
		$a : b : c = 0{\cdot}57735 : 1 : 3{\cdot}2743$	$\beta = 90° 0'$
Phlogopite		$(H,K,(MgF))_3Mg_3Al(SiO_4)_3$	
	Magnesium Mica; usually containing fluorine, nearly free from iron.		
Lepidomelane		Annite.	
	Iron Micas. Contain ferric iron in large amount.		

The species of the Mica Group crystallize in the monoclinic system, but with a close approximation to either rhombohedral or orthorhombic symmetry; the plane angles of the base are in all cases 60° or 120°. They are all characterized by highly perfect basal cleavage, yielding very thin, tough, and more or less elastic laminæ. The negative bisectrix, X, is very nearly normal to the basal plane, varying at most but a few degrees from this; hence a cleavage plate shows the axial interference-figure, which for the pseudo-rhombohedral kinds is often uniaxial or nearly uniaxial. Of the species named above, biotite has usually a very small axial angle, and is often sensibly unaxial; the axial angle of phlogopite is also small, usually 10° to 12°; for muscovite, paragonite, lepidolite the angle is large, in air commonly from 50° to 70°.

The Micas may be referred to the same fundamental axial ratio with an angle of obliquity differing but little from 90°; they show to a considerable extent the same forms, and their isomorphism is further indicated by their not infrequent intercrystallization in parallel position, as biotite with muscovite, lepidolite with muscovite, etc.

945



A blow with a somewhat dull-pointed instrument on a cleavage plate of mica develops in all the species a six-rayed *percussion-figure* (Fig. 945, also Fig. 491, p. 189), two lines of which are nearly parallel to the prismatic edges; the third, which is the most strongly characterized, is parallel to the clinopinacoid or plane of symmetry. The micas are often divided into two classes, according to the position of the plane of the optic axes. In the *first class* belong those kinds for which the optic axial plane is normal to *b* (010), the plane of symmetry (Fig. 945); in the *second class* the axial plane is parallel to the plane of symmetry. The percussion figure serves to fix the crystallographic orientation when crystalline faces are wanting. A second series of lines at right angles to those mentioned may be more or less distinctly developed by pressure of a dull point on an elastic surface, forming the so-called *pressure-figure;* this is sometimes six-rayed, more often shows three branches only, and sometimes only two are developed. In Fig. 945 the position of the pressure-figure is indicated by the broken lines. These lines are connected with gliding-planes inclined some 67° to the plane of cleavage (see beyond).

The micas of the *first class* include: Muscovite, paragonite, lepidolite, also some rare varieties of biotite called anomite.

The *second class* embraces: Zinnwaldite and most biotite, including lepidomelane and phlogopite.

Chemically considered, the micas are silicates, and in most cases orthosilicates, of aluminium with potassium and hydrogen, also often magnesium, ferrous iron, and in certain cases ferric iron, sodium, lithium (rarely rubidium and cæsium); further, rarely, barium, manganese, chromium. Fluorine is prominent in some species, and titanium is also sometimes present. Other elements (boron, etc.) may be present in traces. All micas yield water upon ignition in consequence of the hydrogen (or hydroxyl) which they contain.

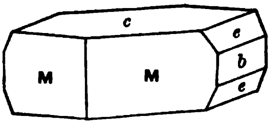
MUSCOVITE. Common Mica. Potash Mica.

Monoclinic. Axes $a \cdot b : c = 0{\cdot}57735 : 1 : 3{\cdot}3128$; $\beta = 89^\circ 54'$.

Twins common according to the *mica-law:* tw. pl. a plane in the zone cM 001 ∧ 221 normal to *c* (001) the crystals often united by *c*. Crystals rhombic or hexagonal in outline with plane angles of 60° or 120°. Habit tabular, passing into tapering forms with planes more or less rough and strongly striated horizontally; vicinal forms common. Folia often very small and aggregated in stellate, plumose, or globular forms; or in scales, and scaly massive; also cryptocrystalline and compact massive.

Cleavage: basal, eminent. Also planes of secondary cleavage as shown in the percussion-figure (see pp. 559 and 189); natural plates hence often yield narrow strips or thin fibers || axis *b*, and less distinct in directions inclined 60° to this. Thin laminæ flexible and elastic when bent, very tough, harsh to the touch, passing into kinds which are less elastic and have a more or less unctuous or talc-like feel. Etching-figures on *c* (001), monoclinic in symmetry (Fig. 495, p. 190).

946



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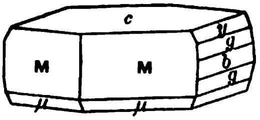


cM, $001 \wedge 221 = 85^\circ 36'$.
$c\mu$, $001 \wedge \bar{1}11 = 81^\circ 30'$.
MM', $221 \wedge 2\bar{2}1 = 59^\circ 48'$.
$\mu\mu'$, $\bar{1}11 \wedge \bar{1}\bar{1}1 = 59^\circ 16\frac{1}{2}'$.

H. = 2–2·5. G. = 2·76–3. Luster vitreous to more or less pearly or silky. Colorless, gray, brown, hair-brown, pale green, and violet, yellow, dark olive-green, rarely rose-red. Streak uncolored. Transparent to translucent.

Pleochroism usually feeble; distinct in some deep-colored varieties (see beyond). Absorption in the direction normal to the cleavage plane (vibrations || Y, Z) strong, much more so than transversely (vibrations || X); hence a crystal unless thin is nearly or quite opaque in the first direction though translucent through the prism. Optically –. Ax. pl. $\perp$ *b* (010) and nearly $\perp$ *c* (001). Bx_a (= *X*) inclined about – 1° (behind) to a normal to *c* (001). Dispersion $\rho > v$. 2V variable, usually about 40°, but diminishing in kinds (phengite) relatively high in silica. α = 1·561. β = 1·590. γ = 1·594.

Var. — 1. *Ordinary Muscovite.* In crystals as above described, often tabular ∥ *c* (001), also tapering with vertical faces rough and striated; the basal plane often rough unless as developed by cleavage. More commonly in plates without distinct outline, except as developed by pressure (see above); the plates sometimes very large, but passing into fine scales arranged in plumose or other forms. In normal muscovite the thin laminæ spring back with force when bent, the scales are more or less harsh to the touch, unless very small, and a pearly luster is seldom prominent.

2. DAMOURITE. Including *margarodite, gilbertite, hydro-muscovite,* and most HYDRO-MICA in general. Folia less elastic; luster somewhat pearly or silky and feel unctuous like talc. The scales are usually small and it passes into forms which are fine scaly or fibrous, as *sericite,* and finally into the compact crypto-crystalline kinds called *oncosine,* including much *pinite.* Often derived by alteration of cyanite, topaz, corundum, etc. Although often spoken of as *hydrous* micas, it does not appear that damourite and the allied varieties necessarily contain more water than ordinary muscovite; they may, however, give it off more readily.

Margarodite, as originally named, was the talc-like mica of Mt. Greiner in the Zillertal, Tyrol, Austria; granular to scaly in structure, luster pearly, color grayish white. *Gilbertite* occurs in whitish, silky forms from the tin mine of St. Austell, Cornwall. *Sericite* is a fine scaly muscovite united in fibrous aggregates and characterized by its silky luster (hence the name from *σηρικός, silky*).

Comp. — For the most part an orthosilicate of aluminium and potassium $(H,K)AlSiO_4$. If, as in the common kinds, H : K = 2 : 1, this becomes $H_2KAl_3(SiO_4)_3 = 2H_2O.K_2O.3Al_2O_3.6SiO_2$ = Silica 45·2, alumina 38·5, potash 11·8, water 4·5 = 100.

Some kinds give a larger amount of silica (47 to 49 p. c.) than corresponds to a normal orthosilicate, and they have been called *phengite.* As shown by Clarke, these acid muscovites can be most simply regarded as molecular mixtures of $H_2KAl_3(SiO_4)_3$ and $H_2KAl_3(Si_3O_8)_3$.

Iron is usually present in small amount only. Barium is rarely present, as in *oellacherite.* G. = 2·88–2·99. Chromium is also present in *fuchsite* from Schwarzenstein, Zillertal, Tyrol, and elsewhere.

Pyr., etc. — In the closed tube gives water. B.B. whitens and fuses on the thin edges (F. = 5·7) to a gray or yellow glass. With fluxes gives reactions for iron and sometimes manganese, rarely chromium. Not decomposed by acids. Decomposed on fusion with alkaline carbonates.

Diff. — Distinguished in normal kinds from all but the species of this division by the perfect basal cleavage and micaceous structure, the pale color separates it from most biotite; the laminæ are more flexible and elastic than those of phlogopite and still more than those of the brittle micas and the chlorites.

Micro. — In thin sections recognized by want of color and by the perfect cleavage shown by fine lines (as in Fig. 951, p. 564) in sections $\perp$ *c* (001), in a direction parallel to *c*. By reflected light under the microscope the same sections show a peculiar mottled surface with satin-like luster; birefringence rather high, hence interference-colors bright.

Obs. — Muscovite is the most common of the micas. It is an essential constituent of mica schist and related rocks, and is a prominent component of certain common varieties of granite and gneiss; also found at times in fragmental rocks and limestones; in volcanic rocks it is rare and appears only as a secondary product. The largest and best developed crystals occur in the pegmatite dikes associated with granitic intrusions, either directly cutting the granite or in its vicinity. Often in such occurrences in enormous plates from which the mica or "isinglass" of commerce is obtained. It is then often associated with crystallized orthoclase, quartz, albite; also apatite, tourmaline, garnet, beryl, columbite, etc., and other mineral species characteristic of granitic veins. Further, muscovite often encloses flattened crystals of garnet, tourmaline, also quartz in thin plates between the sheets; further not infrequently magnetite in dendrite-like forms following in part the directions of the percussion-figure.

Some of the best known localities, are: Abühl in the Sulzbachtal, Austrian Tyrol; with adularia; Rothenkopf in the Zillertal, Tyrol; Soboth, Styria; St. Gothard, Binnental, and elsewhere in Switzerland; Mourne Mts., Ireland; Cornwall; Utö, Falun, Sweden; Skutterud, and Bamble, Norway. Obtained in large plates from Greenland and the East Indies.

In Me., at Mount Mica in the town of Paris; at Buckfield, in fine crystals. In N. H., at Acworth, Grafton. In Mass., at Chesterfield; South Royalston; at Goshen, rose-red. In Conn., at Monroe; at Litchfield, with cyanite; at the Middletown feldspar quarry; at Haddam; at Branchville, with albite, etc.; New Milford. In N. Y., near Warwick; Edenville; Edwards. In Pa., at Pennsbury, Chester Co.; at Unionville, Delaware Co., and at Middletown. In Md., at Jones's Falls, Baltimore. In Va., at Amelia Court-House. In N. C., extensively mined at many places in the western part of the state; the chief mines are in Mitchell, Yancey, Jackson and Macon Cos.; crystals from Lincoln Co. The mica mines have also afforded many rare species, as columbite, samarskite, hatchettolite, uraninite, etc.; in good crystals in Alexander Co. In S. C., there are also muscovite deposits; also in Ga. and Ala.

Mica mines have also been worked to some extent in the Black Hills, S. D.; in Wash., at Rockford, Spokane Co.; in Col. The important states for the production of mica are North Carolina, New Hampshire, Idaho, South Dakota, Virginia, Alabama, New York, Connecticut.

Muscovite is named from *Vitrum Muscoviticum* or *Muscovy-glass*, formerly a popular name of the mineral.

Use. — As an insulating material in electrical apparatus; as a non-inflammable transparent material for furnace doors, etc.; in a finely divided form as a non-conductor of heat and fireproofing material; mixed with oil as a lubricant, etc.

Pinite. A general term used to include a large number of alteration-products especially of iolite, also spodumene, nephelite, scapolite, feldspar and other minerals. In composition essentially a hydrous silicate of aluminium and potassium corresponding more or less closely to muscovite, of which it is probably to be regarded as a massive, compact variety, usually very impure from the admixture of clay and other substances. Characters as follows: Amorphous; granular to cryptocrystalline. Rarely a submicaceous cleavage. H. = 2·5–3·5. G. = 2·6–2·85. Luster feeble, waxy. Color grayish white, grayish green, pea-green, dull green, brownish, reddish. Translucent to opaque. The following are some of the minerals also classed as pinite: *gigantolite*, *gieseckite* (see p. 500), *liebenerite*, *dysyntribite*, *parophite*, *rosite*, *polyargite*, *wilsonite*, *killinite*.

Agalmatolite (pagodite) is like ordinary massive pinite in its amorphous compact texture, luster, and other physical characters, but contains more silica, which may be from free quartz or feldspar as impurity. The Chinese has H. = 2–2·5; G. = 2·785–2·815. Colors usually grayish, grayish green, brownish, yellowish. Named from *ἄγαλμα, an image*; *pagodite* is from *pagoda*, the Chinese carving the soft stone into miniature pagodas, images, etc. Part of the so-called agalmatolite of China is true pinite in composition, another part is compact pyrophyllite, and still another steatite (see these species).

Paragonite. A sodium mica, corresponding to muscovite in composition; formula, $H_2NaAl_3(SiO_4)_3$. In fine pearly scales; also compact. G. = 2·78–2·90. Index, 1·60. Color yellowish, grayish, greenish; constitutes the mass of the rock at Monte Campione near Faido in Canton Tessin, Switzerland, containing cyanite and staurolite; called paragonite-schist. Occurs associated with tourmaline and corundum at Unionville, Delaware Co., Pa. *Hallerite*, a mica with an iridescent silver color and pearly luster. Perhaps a lithium-bearing *paragonite*. Found at Mesores, near Autun, France.

BADDECKITE, an iron mica related to muscovite. In small scales with a copper-red color. From near Baddeck, Nova Scotia.

LEPIDOLITE. Lithia Mica.

In aggregates of short prisms, often with rounded terminal faces. Crystals sometimes twins or trillings according to the mica law. Also in cleavable plates, but commonly massive scaly-granular, coarse or fine.

Cleavage: basal, highly eminent. H. = 2·5–4. G. = 2·8–2·9. Luster pearly. Color rose-red, violet-gray or lilac, yellowish, grayish white, white. Translucent. Optically −. Ax. pl. usually ⊥ *b* (010); rarely || *b*. Bx$_a$ (*X*) inclined 1° 47′ red, and 1° 33½′ yellow to normal to *c* (001). Axial angle large, from 50°–72°, β = 1·5975.

Comp. — In part a metasilicate, $\overset{\mathrm{I}}{\mathrm{R}}_3Al(SiO_3)_3$ or $KLi[Al(OH,F)_2]Al(SiO_3)_3$. The ratio of fluorine and hydroxyl is variable.

It has been suggested that the pure lepidolite molecule is represented by $3Li_2O.2K_2O.3Al_2O_3.8F.12SiO_2$ and that most lepidolites are mixtures of this and the muscovite molecule.

Pyr., etc. — In the closed tube gives water and reaction for fluorine. B.B. fuses with intumescence at 2–2·5 to a white or grayish glass sometimes magnetic, coloring the flame purplish red at the moment of fusion (lithia). With the fluxes some varieties give reactions for iron and manganese. Attacked but not completely decomposed by acids. After fusion, gelatinizes with hydrochloric acid.

Obs. — Occurs in granite and gneiss, especially in granitic veins; often associated with lithia-tourmaline; also with amblygonite, spodumene, cassiterite, etc.; sometimes associated with muscovite in parallel position.

Found near Utö in Sweden; Penig, Saxony; Rozena (or Rožna), Moravia; Madagascar, etc. In the United States, common in the western part of Me., in Hebron, Auburn, Paris, etc.; at Chesterfield, Mass.; Middletown and Haddam Neck, Conn.; with rubellite near San Diego, Cal.

Named lepidolite from λεπίς, *scale*, after the earlier German name *Schuppenstein*, alluding to the scaly structure of the massive variety of Rozena.

Use. — As a source of lithium compounds.

Cookeite is a micaceous mineral occurring in rounded aggregations on rubellite, also with lepidolite, tourmaline, etc., at Hebron, Me. An alteration of lepidolite or tourmaline. Composition $Li[Al(OH)_2]_3(SiO_3)_2$.

Zinnwaldite. An iron-lithia mica in form near biotite. Color pale violet, yellow to brown and dark gray. Occurs at Zinnwald and Altenberg, Germany; similarly in Cornwall, England. From Narsarsuk, Greenland, and the York region, Alaska.

Cryophyllite is a related lithium mica from Rockport, Mass. *Polylithionite* is a lithium mica from Kangerdluarsuk, Greenland. *Irvingite* is an alkalie mica containing lithium from near Wausau, Wis.

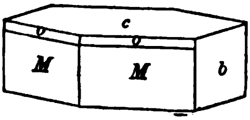
Manandonite. A basic boro-silicate of lithium and aluminium, $H_{24}Li_4Al_{14}B_4Si_6O_{53}$. Micaceous. In lamellar aggregates or mammillary crusts of hexagonal plates. Perfect basal cleavage. Color white. Luster pearly. Optically +. Axial angle small and variable. Easily fusible giving red flame. Unattacked by acids. Found in pegmatite at Antandrokomby, near the Manandona River, Madagascar.

BIOTITE.

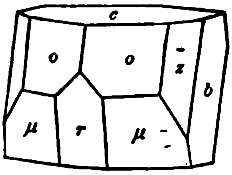
Monoclinic; pseudo-rhombohedral. Axes $a : b : c = 0·57735 : 1 : 3·2743$; $\beta = 90°$.

Habit tabular or short prismatic; the pyramidal faces often repeated in oscillatory combination. Crystals often apparently rhombohedral in symmetry since *r* (101) and *z* (132), *z′* ($1\bar{3}2$), which are inclined to *c* (001) at sensibly the same angle, often occur together; further, the zones to which these faces belong are inclined 120° to each other, hence the hexagonal outline of basal sections. Twins, according to the mica law, tw. pl. a plane in the prismatic zone ⊥ *c* (001). Often in disseminated scales, sometimes in massive aggregations of cleavable scales.

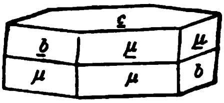
948



949



950



co, $001 \wedge 112 = 73° \ 1'$. *cr*, $001 \wedge \bar{1}01 = 80° \ 0'$.
cM, $001 \wedge 221 = 85° \ 38'$. *cz*, $001 \wedge 132 = 80° \ 0'$.
cμ, $001 \wedge \bar{1}11 = 81° \ 19'$. *MM′*, $221 \wedge \bar{2}21 = 59° \ 48\tfrac{1}{2}'$.

Cleavage: basal, highly perfect; planes of separation shown in the percussion-figure; also gliding-planes ρ ($\bar{2}05$), ζ (135) shown in the pressure-figure inclined about 66° to *c* (001) and yielding pseudo-crystalline forms (Fig. 489, p. 188). H. = 2·5–3. G. = 2·7–3·1. Luster splendent, and more or less pearly on a cleavage surface, and sometimes submetallic when black; lateral surfaces vitreous when smooth and shining. Colors usually green to black, often deep black in thick crystals, and sometimes even in thin laminæ, unless the laminæ are very thin; such thin laminæ green, blood-red, or brown by transmitted light; also pale yellow to dark brown; rarely white. Streak uncolored. Transparent to opaque.

Pleochroism strong; absorption $Y = Z$ nearly, for X much stronger. Hence sections $\parallel$ *c* (001) dark green or brown to opaque; those $\perp$ *c* lighter and deep brown or green for vibrations $\parallel$ *c*, pale yellow, green or red for vibrations $\perp$ *c*. Pleochroic halos often noted, particularly about microscopic inclusions. Optically −. Ax. pl. usually $\parallel$ *b* (010), rarely $\perp$ *b*. Bx_a ($=X$) nearly coincident with the normal to *c* (001), but inclined about half a degree, sometimes to the front, sometimes the reverse. Axial angle usually very small, and often sensibly uniaxial; also up to 50°. Birefringence high, $\gamma - \alpha = 0·04$ to $0·06$.

Comp. — In most cases an orthosilicate, chiefly ranging between $(H,K)_2(Mg,Fe)_4(Al,Fe)_2(SiO_4)_4$ and $(H,K)_2(Mg,Fe)_2Al_2(SiO_4)_3$. Of these the second formula may be said to represent typical biotite. The amount of iron varies widely.

Var. — Biotite is divided into two classes by Tschermak:

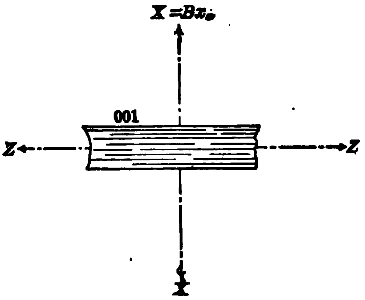
I. Meroxene. Axial plane $\parallel$ *b* (010). II. Anomite. Ax. pl. $\perp$ *b* (010). Of these two kinds, meroxene includes nearly all ordinary biotite, while anomite is, so far as yet observed, of restricted occurrence, the typical localities being Greenwood Furnace, Orange Co., N. Y., and Lake Baikal in East Siberia. *Meroxene* is a name early given to the Vesuvian biotite. Anomite is from *ανομος*, contrary to law.

Haughtonite and *Siderophyllite* are kinds of biotite containing much iron.

Manganophyllite is a manganesian biotite. Occurs in aggregations of thin scales. Color bronze- to copper-red. Streak pale red. From Pajsberg and Långban, Sweden; Piedmont, Italy.

Pyr., etc. — In the closed tube gives a little water. Some varieties give the reaction for fluorine in the open tube; some kinds give little or no reaction for iron with the fluxes, while others give strong reactions for iron. B.B. whitens and fuses on the thin edges. Completely decomposed by sulphuric acid, leaving the silica in thin scales.

951



Diff. — Distinguished by its dark green to brown and black color and micaceous structure, usually nearly uniaxial.

Micro. — Recognized in thin sections by its brown (or green) color; strong pleochroism and strong absorption parallel to the elongation (unlike tourmaline). Sections $\parallel$ *c* (001) are non-pleochroic, commonly exhibit more or less distinct hexagonal outlines and yield a negative sensibly uniaxial figure. Sections $\perp$ *c* are strongly pleochroic and are marked by fine parallel cleavage lines (Fig. 951); they also have nearly parallel extinction, and show high polarization colors; by reflected light they exhibit a peculiar mottled or watered sheen which is very characteristic and aids in distinguishing them from brown hornblende.

Obs. — Biotite is an important constituent of many different kinds of igneous rocks, especially those formed from magmas containing considerable potash and magnesia. Common in certain varieties of granites, syenite, diorite, etc., of the massive granular type; also in rhyolite, trachyte, and andesite among the lavas; in minettes, kersantites, etc. It occurs also as the product of metamorphic action in a variety of rocks. It is not infrequently associated in parallel position with muscovite, the latter, for example, forming the outer portions of plates having a nucleus of biotite.

Some of the prominent localities of crystallized biotite are as follows: Vesuvius, common particularly in ejected limestone masses on Monte Somma, with augite, chrysolite, nephelite, humite, etc. The crystals are sometimes nearly colorless or yellow and then usually complex in form; also dark green to black; Mt. Monzoni in the Fassatal and Schwarzenstein, Zillertal, Tyrol, Austria; Rezbánya and Morawitza in Hungary; in Germany at Schelingen and other points in the Kaiserstuhl and the Laacher See; on the west side of Lake Ilmen near Miask, Russia.

In the United States ordinary biotite is common in granite, gneiss, etc.; but notable localities of distinct crystals are not numerous. It occurs with muscovite (which see) as a more or less prominent constituent of the pegmatite veins in the New England States; also Pennsylvania, Virginia, North Carolina. From Greenwood, Orange Co., N. Y. *Siderophyllite* is from the Pike's Peak region, Col.

CASWELLITE. An altered biotite from Franklin Furnace, N. J.

PHLOGOPITE.

Monoclinic. In form and angles near biotite. Crystals prismatic, tapering; often large and coarse; in scales and plates.

Cleavage: basal, highly eminent. Thin laminæ tough and elastic. H. = 2·5–3. G. = 2·78–2·85. Luster pearly, often submetallic on cleavage surface. Color yellowish brown to brownish red, with often something of a copper-like reflection; also pale brownish yellow, green, white, colorless. Often exhibits asterism in transmitted light, due to regularly arranged inclusions. Pleochroism distinct in colored varieties: *Z* brownish red, *Y* brownish green, *X* yellow. Absorption $Z > Y > X$. Optically −. Ax. pl. $\parallel$ *b* (010). Bx_a nearly $\perp$ *c* (001). Axial angle small but variable even in the same specimen, from 0° to 50°. Dispersion $\rho < v$. The axial angle appears to increase with the amount of iron. Indices variable, from 1·541–1·638.

Comp. — A magnesium mica, near biotite, but containing little iron; potassium is prominent as in all the micas, and in most cases fluorine. Typical phlogopite is $\overset{I}{R}_3Mg_3Al(SiO_4)_3$, where $\overset{I}{R}$ = H,K,MgF.

Obs. — Phlogopite is especially characteristic of crystalline limestone or dolomite. It is often associated with pyroxene, amphibole, serpentine, etc. Thus as at Pargas, Finland; in St. Lawrence Co. and Jefferson Co., N. Y.; Franklin, N. J.; also Burgess, Ontario, and elsewhere in Canada.

Named from φλογωπός, *fire-like*, in allusion to the color.

The asterism of phlogopite, seen when a candle-flame is viewed through a thin sheet, is a common character, particularly prominent in the kinds from northern New York and Canada. It has been shown to be due to minute acicular inclusions, rutile or tourmaline, arranged chiefly in the direction of the rays of the pressure-figure, producing a distinct six-rayed star; also parallel to the lines of the percussion-figure, giving a secondary star, usually less prominent than the other.

Tæniolite. Essentially a potassium-magnesium silicate. Monoclinic, belonging to the mica group. Perfect basal cleavage. Folia somewhat elastic. H. = 2·5–3. G. = 2·9. Colorless. Fusible. From Narsarsuk, southern Greenland.

Lepidomelane. Near biotite, but characterized by the large amount of ferric iron present. From Langesund fiord, Norway; Haddam, Conn. *Annite* from Cape Ann, Mass., belongs here. In small six-sided tables, or an aggregate of minute scales. H. = 3. G. = 3·0–3·2. Color black, with occasionally a leek-green reflection.

Alurgite. A manganese mica from St. Marcel, Piedmont, Italy. Color copper-red. Index, 1·59. *Mariposite* may belong here.

Roscoelite. A vanadium mica; essentially a muscovite in which vanadium has partly replaced the aluminium. In minute scales; structure micaceous. G. = 2·92–2·94. Color clove-brown to greenish brown. Indices, 1·610–1·704. Occurs in Cal. at the gold mine at Granite Creek, Placerville, and elsewhere, El Dorado Co.

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2. *Clintonite Group.* Monoclinic

The minerals here included are sometimes called the Brittle Micas. They are near the micas in cleavage, crystalline form and optical properties, but are marked physically by the brittleness of the laminæ, and chemically by their basic character.

In several respects they form a transition from the micas proper to the chlorites. Margarite, or calcium mica, is a basic silicate of aluminium and calcium, while Chloritoid is a basic silicate of aluminium and ferrous iron (with magnesium), like the chlorites.

MARGARITE.

Monoclinic. Rarely in distinct crystals. Usually in intersecting or aggregated laminæ; sometimes massive, with a scaly structure.

Cleavage: basal, perfect. Laminæ rather brittle. H. = 3·5–4·5. G. = 2·99–3·08. Luster of base pearly, of lateral faces vitreous. Color grayish, reddish white, pink, yellowish. Translucent, subtranslucent.

Optically −. Ax. pl. ⊥ *b* (010). Bx_a approximately ⊥ *c* (001), but varying more widely than the ordinary micas. $X \wedge c$ axis = + 6½°. Dispersion $\rho < v$. Axial angle large, from 76° to 128° in air. Refractive index β = 1·64–1·65.

Comp. — $H_2CaAl_4Si_2O_{12}$ = Silica 30·2, alumina 51·3, lime 14·0, water 4·5 = 100.

Pyr., etc. — Yields water in the closed tube. B.B. whitens and fuses on the edges. Slowly and imperfectly decomposed by boiling hydrochloric acid.

Obs. — Associated commonly with corundum, and in many cases obviously formed directly from it; thus at the emery deposits of Gumuch-dagh in Asia Minor, the islands Naxos, Nicaria, etc. Occurs in chlorite of Mt. Greiner, Sterzing, Tyrol. In the United States at the emery mine at Chester, Mass.; at Unionville, Chester Co., Pa.; with corundum in Madison Co. and elsewhere in N. C.; at Gainesville, Hall Co., Ga.; at Dudleyville, Ala.

Named *Margarite* from *μαργαρίτης, pearl.*

SEYBERTITE. Clintonite. Brandisite.

Monoclinic, near biotite in form. Also foliated massive; sometimes lamellar-radiate.

Cleavage: basal, perfect. Structure foliated, micaceous. Laminæ brittle. Percussion- and pressure-figures, as with mica. H. = 4–5. G. = 3–3·1. Luster pearly submetallic. Color reddish brown, yellowish, copper-red. Streak uncolored, or slightly yellowish or grayish. Pleochroism rather feeble. Optically −. Ax. pl. ⊥ *b* (010) *seybertite;* || *b brandisite.* Bx_a nearly ⊥ *c* (001). Axial angles variable, but not large. α = 1·646. β = 1·657. γ = 1·658.

Var. — 1. The Amity *seybertite* (*clintonite*) is in reddish brown to copper-red brittle foliated masses; the surfaces of the folia often marked with equilateral triangles like some mica and chlorite. Axial angle 3°–13°.

2. *Brandisite* (*disterrite*), from the Fassatal, Tyrol, is in hexagonal prisms of a yellowish green or leek-green color to reddish gray; H. = 5 of base; of sides, 6–6·5. Ax. pl. || *b* (010). Axial angle 15°–30°. Some of it pseudomorphous, after fassaite.

Comp. — In part $H_3(Mg,Ca)_5Al_5Si_2O_{18} = 3H_2O.10(Mg,Ca)O.5Al_2O_3.4SiO_2$.

Pyr., etc. — Yields water. B.B. infusible but whitens. In powder acted on by concentrated acids.

Obs. — *Seybertite* occurs at Amity, N. Y., in limestone with serpentine, associated with amphibole, spinel, pyroxene, graphite, etc.; also a chlorite near leuchtenbergite. *Brandisite* occurs on Mt. Monzoni in the Fassatal, Tyrol, Austria, in white limestone, with fassaite and black spinel.

Xanthophyllite. Perhaps $H_8(Mg,Ca)_{14}Al_{16}Si_5O_{52}$. The original *xanthophyllite* is in crusts or in implanted globular forms. Optically negative. Axial angle usually very small, or sensibly uniaxial; sometimes 20°. Indices, 1·649–1·661. From near Zlatoust in the Ural Mts. Found at Crestmore, Riverside Co., Cal.

Waluewite is the same species occurring in distinct pseudo-rhombohedral crystals. Folia brittle. H. = 4·6. G. = 3·093. Luster vitreous; on cleavage plane pearly. Color leek- to bottle-green. Transparent to translucent. Pleochroism rather feeble: $\parallel$ *c* axis fine green; $\perp$ *c* axis reddish brown. Optically −. Ax. pl. $\parallel$ *b* (010). Bx sensibly $\perp$ *c* (001). Axial angle 17° to 32°. Found with perovskite and other species in chloritic schists near Achmatovsk, in the southern Ural Mts.

CHLORITOID. Ottrelite. Phyllite.

Probably triclinic. Rarely in distinct tabular crystals, usually hexagonal in outline, often twinned with the individuals turned in azimuth 120° to each other. Crystals grouped in rosettes. Usually coarsely foliated massive; folia often curved or bent and brittle; also in thin scales or small plates disseminated through the containing rock.

Cleavage: basal, but less perfect than with the micas; also imperfect parallel to planes inclined to the base nearly 90° and to each other about 60°; *b* (010) difficult. Laminæ brittle. H. = 6·5. G. = 3·52–3·57. Color dark gray, greenish gray, greenish black, grayish black, often grass-green in very thin plates. Streak uncolored, or grayish, or very slightly greenish. Luster of surface of cleavage somewhat pearly.

Pleochroism strong: Z yellow green, Y indigo-blue, X olive-green. Optically +. Ax. pl. nearly $\parallel$ *b* (010). Bx_a inclined about 12° or more to the normal to *c* (001). Dispersion $\rho > v$, large, also horizontal. Axial angles, in air 65° to 120°. $\beta = 1·75$. Birefringence low, $\gamma - \alpha = 0·007–0·016$.

Comp. — For chloritoid $H_2(Fe,Mg)Al_2SiO_7$. If iron alone is present, this requires: Silica 23·8, alumina 40·5, iron protoxide 28·5, water 7·2 = 100.

Micro. — Recognized in thin sections by the crystal outlines and general micaceous appearance; high relief; green colors; distinct cleavage; frequent twinning; strong phleochroism and low interference-colors. By the last character readily distinguished from the micas; also by the high relief and extinction oblique to the cleavage from the chlorites.

Obs. — Chloritoid (ottrelite, etc.) are characteristic of sedimentary rocks which have suffered dynamic metamorphism, especially in the earlier stages; thus found in argillites, conglomerates, etc., which have assumed the schistose condition. With more advanced degree of metamorphism it disappears. Often grouped in fan-shaped, sheaf-like forms, also in irregular or rounded grains.

The original *chloritoid* from Kosoibrod, near Ekaterinburg in the Ural Mts., is in large curving laminæ or plates, grayish to blackish green in color, often spotted with yellow from mixture with limonite. Other localities are Ile le Groix (Morbihan), France; embedded in large crystals at Vanlup, Shetland; Ardennes, France, and Belgium, in schists with ottrelite; also from Upper Michigan; Leeds, Canada, etc.

Sismondine ($H_{14}Fe_7Al_{16}Si_8O_{54}$) is from St. Marcel, Piedmont, Italy; it occurs also with glaucophane at Zermatt in the Valais, Switzerland, and elsewhere.

Salmite is a manganesian variety occurring in irregular masses, having a coarse saccharoidal structure and grayish color. G. = 3·38. From Vielsalm, Belgium.

Masonite, from Natic, R. I., is in very broad plates of a dark grayish green color, but bluish green in very thin laminæ parallel to *c* (001) and grayish green at right angles to this; occurs in argillaceous schist.

Ottrelite is generally classed with chloritoid, though it is not certain that they are identical; it seems to have the composition $H_2(Fe,Mn)Al_2Si_2O_9$. It occurs in small, oblong, shining scales or plates, more or less hexagonal in form and gray to black in color; in argillaceous schist near Ottrez, on the borders of Luxemburg, and from the Ardennes, France, and Belgium; also near Serravezza, Tuscany, Italy; Tintagel in Cornwall. *Venasquite* is from Venasque in the Pyrenees, and from Teulé, Finistére, France. *Phyllite* is from the schists of New England.

3. *Chlorite Group.* Monoclinic

The CHLORITE GROUP takes its name from the fact that a large part of the minerals included in it are characterized by the *green* color common with silicates in which ferrous iron is prominent. The species are in many respects closely related to the micas. They crystallize in the monoclinic system, but in part with distinct monoclinic symmetry, in part with rhombohedral symmetry, with corresponding uniaxial optical character. The plane angles of the base are also 60° or 120°, marking the mutual inclinations of the chief zones of forms. The mica-like basal cleavage is prominent in distinctly crystallized forms, but the laminæ are tough and comparatively inelastic. Percussion and pressure-figures may be obtained as with the micas and have the same orientation. The etching-figures are in general monoclinic in symmetry, in part also asymmetric, suggesting a reference to the triclinic system.

Chemically considered the chlorites are silicates of aluminium with ferrous iron and magnesium and chemically combined water. Ferric iron may be present replacing the aluminium in small amount; chromium enters similarly in some forms, which are then usually of a pink instead of the more common green color. Manganese replaces the ferrous iron in a few cases. Calcium and alkalies — characteristic of all the true micas — are conspicuously absent, or present only in small amount.

The only distinctly crystallized species of the Chlorite Group are Clinochlore and Penninite. These seem to have the same composition, but while the former is monoclinic in form and habit, the latter is pseudo-rhombohedral and usually uniaxial. Prochlorite (including some ripidolite) and Corundophilite also occur in distinct cleavage masses.

Besides the species named there are other kinds less distinct in form, occurring in scales, also fibrous to massive or earthy; they are often of more or less undetermined composition, but in many cases, because of their extensive occurrence, of considerable geological importance. These latter forms occur as secondary minerals resulting from the alteration especially of ferro-magnesian silicates, such as biotite, pyroxene, amphibole; also garnet, vesuvianite, etc. They are often accompanied by other secondary minerals, as serpentine, limonite, calcite, etc., especially in the altered forms of basic rocks.

The rock-making chlorites are recognized in thin sections by their characteristic appearance in thin leaves, scales or fibers, sometimes aggregated into spherulites; by their greenish color; pleochroism; extinction parallel to the cleavage (unlike chloritoid and ottrelite); low relief and extremely low interference-colors, which frequently exhibit the "ultra-blue." By this latter character they are readily distinguished from the micas, which they strongly resemble and with which they are frequently associated.

CLINOCHLORE. Ripidolite in part.

Monoclinic. Axes $a : b : c = 0{\cdot}57735 : 1 : 2{\cdot}2772$; $\beta = 89° 40'$.

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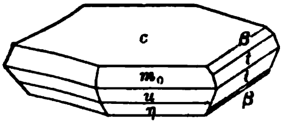

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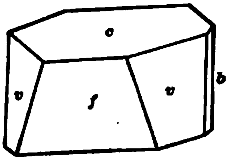

Schwarzenstein

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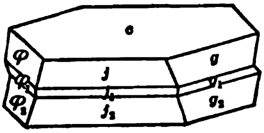

Zillertal

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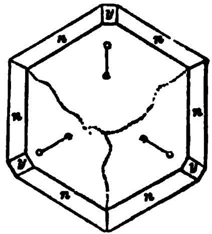

Achmatovsk

Crystals usually hexagonal in form, often tabular || *c* (001). Plane angles of the basal section = 60° or 120°, and since closely similar angles are found in the zones which are separated by 60°, the symmetry approximates to that of the rhombohedral system.

Twins: (1) *Mica law*, tw. pl. ⊥ *c* (001) in the zone cm_0 001 ∧ 112; sometimes contact-twins with *c* as composition face, the one part revolved 60° or a multiple of 60° in azimuth with reference to the other; also in three-fold twins. (2) *Penninite law*, tw. pl. *c*, contact-twins also united by *c* (Fig. 954); here corresponding faces differ 180° in position. Massive, coarse scaly granular to fine granular and earthy.

Cleavage: *c* (001) highly perfect. Laminæ flexible tough, and but slightly elastic. Percussion-figure and pressure-figures orientated as with the micas (p. 559). H. = 2–2·5. G. = 2·65–2·78. Luster of cleavage-face somewhat pearly. Color deep grass-green to olive-green; pale green to yellowish and white; also rose-red. Streak greenish white to uncolored. Transparent to translucent. Pleochroism not strong, for green varieties usually *X* green, *Z* yellow. Optically usually +. Ax. pl. in most cases || *b* (010). Bx_a inclined somewhat to the normal to *c* (001), forward; for Achmatovsk 2° 30′. Dispersion $\rho < v$. Axial angles variable, even in the same crystal, 0°–90°; sometimes sensibly uniaxial. Birefringence low. Indices approximately; $\alpha = 1{\cdot}585$. $\beta = 1{\cdot}586$. $\gamma = 1{\cdot}596$.

Var. — 1. *Ordinary*; green clinochlore, passing into bluish green; (*a*) in crystals, as described, usually with distinct monoclinic symmetry; (*b*) foliated; (*c*) massive.

Leuchtenbergite. Contains usually little or no iron. Color white, pale green, yellowish; often resembles talc. From near Zlatoust in the Ural Mts.

Kotschubeite. Contains several per cent of chromium oxide. Crystals rhombohedral in habit. Color rose-red. From the southern Ural Mts.

Manganiferous. Manganchlorite. A chlorite from the Harstig mine near Pajsberg, Sweden, is peculiar in containing 2·3 p. c. MnO.

Comp. — Normally $H_8Mg_5Al_2Si_3O_{18} = 4H_2O.5MgO.Al_2O_3.3SiO_2$ = Silica 32·5, alumina 18·4, magnesia 36·1, water 13·0 = 100. Ferrous iron usually replaces a small part of the magnesia, and the same is true of manganese rarely; sometimes chromium replaces the aluminium.

Pyr., etc. — Yields water. B.B. in the platinum forceps whitens and fuses with difficulty on the edges to a grayish black glass. With borax, a clear glass colored by iron, and sometimes chromium. In sulphuric acid wholly decomposed.

Micro. — In thin sections characterized by pale green color and pleochroism; distinctly biaxial and usually +.

Obs. — Occurs in connection with chloritic and talcose rocks or schists and serpentine; sometimes in parallel position with biotite or phlogopite. Prominent localities are: Achmatovsk in the Ural Mts.; Ala in Piedmont, Italy; the Zillertal, Tyrol, Austria; Zermatt, Switzerland; Marienberg, Saxony; Zöptau, Moravia. A manganesian variety occurs at Pajsberg, Sweden.

In the United States, at Westchester, Pa., in large crystals and plates; also Unionville and Texas, Pa.; at the magnetic iron mine at Brewster, N. Y., in part changed to serpentine; near Lowell, Ver., in crystals.

PENNINITE. Pennine.

Apparently rhombohedral in form but strictly pseudo-rhombohedral and monoclinic.

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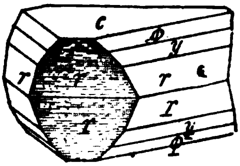

Texas

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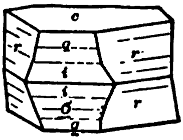

Zermatt

Habit rhombohedral: sometimes thick tabular with *c* (001) prominent, again steep rhombohedral; also in tapering six-sided pyramids. Rhombohedral faces often horizontally striated. Crystals often in crested groups. Also massive, consisting of an aggregation of scales; also compact cryptocrystalline.

Cleavage: *c* (001) highly perfect. Laminæ flexible. Percussion-figure and pressure-figure as with clinochlore but less easy to obtain; not elastic. H. = 2–2·5. G. = 2·6–2·85. Luster of cleavage-surface pearly; of lateral plates vitreous, and sometimes brilliant. Color emerald- to olive-green; also violet, pink, rose-red, grayish red; occasionally yellowish and silver-white. Transparent to subtranslucent. Pleochroism distinct: usually || *c* (001) green; ⊥ *c* yellow. Optically +, also −, and sometimes both in adjacent laminæ of the same crystal. Usually sensibly uniaxial, but sometimes distinctly biaxial (occasionally 2E = 61°) and both in the same section. Sometimes a uniaxial nucleus while the border is biaxial with 2E = 36°, the latter probably to be referred to clinochlore. Indices 1·576 and 1·579.

Var. — 1. *Penninite*, as first named, included a green crystallized chlorite from the Penninine Alps.

Kämmererite. In hexagonal forms bounded by steep six-sided pyramids. Color kermes-red; peach-blossom-red. Pleochroism distinct. Optically − from Lake Itkul, Bisersk, Perm, Russia; + Texas, Pa. Uniaxial or biaxial with axial angle up to 20°. Rhodophyllite from Texas, Pa., and rhodochrome from Lake Itkul belong here.

Pseudophite is compact massive, without cleavage, and resembles serpentine.

Comp. — Essentially the same as clinochlore, $H_8(Mg,Fe)_5Al_2Si_3O_{18}$.

Pyr., etc. — In the closed tube yields water. B.B. exfoliates somewhat and is difficultly fusible. With the fluxes all varieties give reactions for iron, and many varieties react for chromium. Partially decomposed by hydrochloric and completely by sulphuric acid.

Micro. — In thin sections shows pale green color and pleochroism; usually nearly uniaxial, −.

Obs. — Occurs with serpentine in the region of Zermatt, Valais, Switzerland, near Mt. Rosa, especially in the moraines of the Findelen glacier; crystals from Zermatt are sometimes 2 in. long and 1½ in. thick; also at the foot of the Simplon Pass, Switzerland; at Ala, Piedmont, Italy, with clinochlore; at Schwarzenstein in Tyrol, Austria; at Taberg in Wermland, Sweden; at Snarum, Norway, greenish and foliated.

Kämmererite is found at the localities already mentioned; also near Miask in the Ural Mts.; at Haroldswick in Unst, Shetland Isles. In large crystals enclosed in the talc in crevices of the chromite from Kraubat, Styria. Abundant at Texas, Lancaster Co., Pa., along with clinochlore, some crystals being embedded in clinochlore, or the reverse. Also in N. C., with chromite at Culsagee, Macon Co.; Webster, Jackson Co.; and other points. From Washington, Cal.

PROCHLORITE. Ripidolite in part.

Monoclinic. In six-sided tables or prisms, the side planes strongly furrowed and dull. Crystals often implanted by their sides, and in divergent groups, fan-shaped, vermicular, or spheroidal. Also in large folia. Massive, foliated, or granular.

H. = 1–2. G. = 2·78–2·96. Translucent to opaque; transparent only in very thin folia. Luster of cleavage surface feebly pearly. Color green, grass-green, olive-green, blackish green; across the axis by transmitted light sometimes red. Streak uncolored or greenish. Laminæ flexible, not elastic. Pleochroism distinct. Optically + in most cases. Bx inclined to the normal to *c* (001) some 2°. Axial angle small, often nearly uniaxial; again 2E = 23°–30°. Dispersion $\rho < v$.

Comp. — Lower in silicon than clinochlore, and with ferrous iron usually, but not always, in large amount.

Obs. — Like other chlorites in modes of occurrence. Occasionally formed from amphibole. Sometimes in implanted crystals, as at St. Gothard, Switzerland, enveloping often adularia, etc.; Mt. Greiner in the Zillertal, Tyrol, Austria; Rauris in Salzburg, Austria; Traversella in Piedmont, Italy; at Mts. Sept Lacs and St. Cristophe in Dauphiné, France; in Styria, Bohemia. Also massive in Cornwall, England, in tin veins; at Arendal in Norway; Salberg and Dannemora, Sweden; Dognacska, Hungary. In Scotland at various points. In the United States, near Washington, D. C.; on Castle Mt., Batesville, Va., a massive form resembling soapstone, color grayish green, feel greasy; Steele's mine, Montgomery Co., N. C.; also with corundum at the Culsagee mine, in broad plates of a dark green color and fine scaly; it differs from ordinary prochlorite in the small amount of ferrous iron.

Corundophilite. A chlorite occurring in deep green laminæ resembling clinochlore but more brittle; contains but 24 p. c. SiO_2. $\beta = 1·583$. Occurs with corundum at Chester, Mass.

AMESITE. $H_4(Mg,Fe)_2Al_2SiO_9$. Silica 21·4 p. c. In hexagonal plates, foliated, resembling the green talc from the Tyrol. H. = 2·5–3. G. = 2·71. Color apple-green. Luster pearly on cleavage face. Optically +, sensibly uniaxial. Occurs with diaspore at Chester, Mass.

SHERIDANITE. A chlorite from Sheridan Co., Wy., containing only little iron.

OTHER CHLORITES. Besides the chlorites already described which occur usually in distinct crystals or plates, there are, as noted on p. 568, forms varying from fine scaly to fibrous and earthy, which are prominent in rocks. In some cases they may belong to the species before described, but frequently the want of sufficient pure material has left their composition in doubt. These chlorites are commonly characterized by their green color, distinct pleochroism and low birefringence (p. 568).

The following are names which have been given particularly to the chlorites filling cavities or seams in basic igneous rocks: *aphrosiderite, diabantite, delessite, epichlorite, euralite, chlorophæite, hullite, pycnochlorite.*

The following are other related minerals.

Moravite. $2FeO.2(Al,Fe)_2O_3.7SiO_2.2H_2O$. In lamellar, scaly and granular forms with perfect basal cleavage. H. = 3·5. G. = 2·4. Color iron-black. Fuses difficultly. Found at iron mines of Gobitschau near Sternberg, Moravia.

Cronstedite. $4FeO.2Fe_2O_3.3SiO_2.4H_2O$. Occurs tapering in hexagonal pyramids; also in diverging groups; amorphous. Cleavage: basal, highly perfect. Thin laminæ elastic. G. = 3·34–3·35. Color coal-black to brownish black; by transmitted light in thin scales emerald-green. Streak dark olive-green. $\beta = 1·80$. From Příbram in Bohemia; also in Cornwall, England.

Thuringite. $8FeO.4(Al,Fe)_2O_3.6SiO_2.9H_2O$. Massive; an aggregation of minute pearly scales. Color olive-green to pistachio-green. $\beta = 1·63$. From near Saalfeld, in Thuringia; Hot Springs, Ark., etc.; from the metamorphic rocks on the Potomac, near Harper's

Ferry (*owenite*). *Stilpnochloran* is name given to an alteration product of thuringite from Gobitschau, near Sternberg, Moravia. In yellow to bronze-red scales.

Brunsvigite. $9(Fe,Mg)O.2Al_2O_3.6SiO_2.8H_2O$. In cryptocrystalline and foliated masses, sometimes forming spherical radiated aggregates. Under microscope folia show hexagonal outline. Color olive-green to yellow-green. H. = 1–2. G. = 3·0. Occurs in cavities in the gabbro of the Radautal in the Harz Mts., Germany.

Griffithite. $4(Mg,Fe,Ca)O.(Al,Fe)_2O_3.5SiO_2.7H_2O$. A member of the Chlorite Group. Color dark green. H. = 1. G. = 2·31. Fusible to magnetic slag. Pleochroic, pale yellow, olive-green, brown-green. Indices 1·48–1·57. Occurs in amygdaloidal cavities in basalt from Cahuenga Pass, Griffith Park, Los Angeles, Cal.

Chamosite. Contains iron (FeO) with but little MgO. Occurs compact or oolitic with H. about 3; G. = 3–3·4; color greenish gray to black. From Chamoson, near St. Maurice, in the Valais, Switzerland.

Stilpnomelane. An iron silicate. In foliated plates; also fibrous, or as a velvety coating. G. = 2·77–2·96. Color black, greenish black. Occurs at Obergrund and elsewhere in Silesia; also in Moravia; near Weilburg, Nassau, Germany. *Chalcodite*, from the Sterling Iron mine, in Antwerp, Jefferson Co., N. Y., coating hematite and calcite, is the same mineral in velvety coating of mica-like scales with a bronze color.

Minguétite. A member of Chlorite Group. A silicate of ferric and ferrous iron, intermediate between *stilpnomelane* and *lepidomelane*. G. = 2·86. Color blackish green. Strongly pleochroic, light yellow to opaque black. Optically –. Fuses to a black magnetic enamel. Decomposed by hydrochloric acid. From Minguet mine, near Segré, Maine-et-Loire, France.

Strigovite. $H_4Fe_2(Al,Fe)_2Si_2O_{11}$. In aggregations of minute crystals. Color dark green. Occurs as a fine coating over the minerals in cavities in the granite of Striegau in Silesia.

Rumpfite. Probably a variety of clinochlore. Massive; granular, consisting of very fine scales. Color greenish white. Occurs with talc near St. Michael and elsewhere in Styria.

Spodiophyllite. $(Na_2,K_2)_2(Mg,Fe)_3(Fe,Al)_2(SiO_3)_8$. In rough hexagonal prisms. Micaceous cleavage. Laminæ brittle. H. = 3–3·2. G. = 2·6. Color ash-gray. Fusible. From Narsarsuk, southern Greenland.

APPENDIX TO THE MICA DIVISION. — VERMICULITES.

The **Vermiculite Group** includes a number of micaceous minerals, all hydrated silicates, in part closely related to the chlorites, but varying somewhat widely in composition. They are alteration-products chiefly of the micas, biotite, phlogopite, etc., and retain more or less perfectly the micaceous cleavage, and often show the negative optical character and small axial angle of the original species. Many of them are of a more or less indefinite chemical nature, and the composition varies with that of the original mineral and with the degree of alteration.

The laminæ in general are soft, pliable, and inelastic; the luster pearly or bronze-like, and the color varies from white to yellow and brown. Heated to 100°–110° or dried over sulphuric acid most of the vermiculites lose considerable water, up to 10 p. c., which is probably hygroscopic; at 300° another portion is often given off; and at a red heat a somewhat larger amount is expelled. Connected with the loss of water upon ignition is the common physical character of exfoliation; some of the kinds especially show this to a marked degree, slowly opening out, when heated gradually, into long worm-like threads. This character has given the name to the group, from the Latin *vermiculari, to breed worms*. The minerals included can hardly rank as distinct species and only their names can be given here: *Jefferisite, vermiculite, culsageeite, kerrite, lennilite, hallite, philadelphite, vaalite, maconite, dudleyite, pyrosclerite.*

III. Serpentine and Talc Division

The leading species belonging here, Serpentine and Talc, are closely related to the Chlorite Group of the Mica Division preceding, as noted beyond. Some other magnesium silicates, in part amorphous, are included with them.

SERPENTINE.

Monoclinic. In distinct crystals, but only as pseudomorphs. Sometimes foliated, folia rarely separable; also delicately fibrous, the fibers often easily separable, and either flexible or brittle. Usually massive, but microscopically finely fibrous and felted, also fine granular to impalpable or cryptocrystalline; slaty. Crystalline in structure but often by compensation nearly isotropic; amorphous.

Cleavage b (010), sometimes distinct; also prismatic (50°) in chrysotile. Fracture usually conchoidal or splintery. Feel smooth, sometimes greasy. H. = 2·5–4, rarely 5·5. G. = 2·50–2·65; some fibrous varieties 2·2–2·3; retinalite, 2·36–2·55. Luster subresinous to greasy, pearly, earthy; resin-like, or wax-like; usually feeble. Color leek-green, blackish green; oil- and siskin-green; brownish red, brownish yellow; none bright; sometimes nearly white. On exposure, often becoming yellowish gray. Streak white, slightly shining. Translucent to opaque.

Pleochroism feeble. Optically −, perhaps also + in chrysotile. Double refraction weak. Ax. pl. $\parallel a$ (100). Bx (X) $\perp b$ (010) the cleavage surface; $Z \parallel$ elongation of fibers. Biaxial, angle variable, often large; 2V = 20° to 90°. Indices variable, from 1·490–1·571.

Var. — Many unsustained species have been made out of serpentine, differing in structure (massive, slaty, foliated, fibrous), or, as supposed, in chemical composition; and these now, in part, stand as varieties, along with some others based on variations in texture, etc.

A. In Crystals — Pseudomorphs. The most common have the form of chrysolite. Other kinds are pseudomorphs after pyroxene, amphibole, spinel, chondrodite, garnet, phlogopite, etc. *Bastite* or *Schiller Spar* is enstatite (hypersthene) altered more or less completely to serpentine. See p. 474.

B. Massive. 1. *Ordinary massive.* (*a*) *Precious* or *Noble Serpentine* is of a rich oil-green color, of pale or dark shades, and translucent even when in thick pieces. (*b*) *Common Serpentine* is of dark shades of color, and subtranslucent. The former has a hardness of 2·5–3; the latter often of 4 or beyond, owing to impurities.

Resinous. Retinalite. Massive, honey-yellow to light oil-green, waxy or resin-like luster.

Bowenite (Nephrite *Bowen*). Massive, of very fine granular texture, and much resembles nephrite, and was long so called. It is apple-green or greenish white in color; G. = 2·594–2·787; and it has the unusual hardness 5·5–6. From Smithfield, R. I.; also a similar kind from New Zealand.

Ricolite is a banded variety with a fine green color from Mexico.

C. Lamellar. *Antigorite*, thin lamellar in structure, separating into translucent folia. H. = 2·5; G. = 2·622; color brownish green by reflected light; feel smooth, but not greasy. From Antigorio valley, Piedmont, Italy.

D. Thin Foliated. *Marmolite*, thin foliated; the laminæ brittle but separable. G. = 2·41; colors greenish white, bluish white to pale asparagus-green. From Hoboken, N. J.

E. Fibrous. *Chrysotile.* Delicately fibrous, the fibers usually flexible and easily separating; luster silky, or silky metallic; color greenish white, green, olive-green, yellow and brownish; G. = 2·219. Often constitutes seams in serpentine. It includes most of the silky *amianthus* of serpentine rocks and much of what is popularly called *asbestus* (asbestos). Cf. p. 489.

Picrolite, columnar, but fibers or columns not easily flexible, and often not easily separable, or affording only a splintery fracture; color dark green to mountain-green, gray, brown. The original was from Taberg, Sweden. *Baltimorite* is picrolite from Bare Hills, Md.

Radiotine is like serpentine except in regard to its solubility and specific gravity. In spherical aggregates of radiating fibers from near Dillenburg, Nassau.

F. Serpentine Rocks. Serpentine often constitutes rock-masses. It frequently occurs mixed with more or less of dolomite, magnesite, or calcite, making a rock of clouded green, sometimes veined with white or pale green, called *verd antique*, *ophiolite*, or *ophicalcite*. Serpentine rock is sometimes mottled with red, or has something of the aspect of a red porphyry; the reddish portions containing an unusual amount of oxide of iron. Any serpentine rock cut into slabs and polished is called *serpentine marble*.

Microscopic examination has established the fact that serpentine in rock-masses has been largely produced by the alteration of chrysolite, and many apparently homogeneous serpentines show more or less of this original mineral. In other cases it has resulted from the alteration of pyroxene or amphibole. Sections of the serpentine derived from chrysolite often show a peculiar structure, like the meshes of a net (Fig. 958); the lines marked by grains of magnetite also follow the original cracks and cleavage directions of the chrysolite (Fig. 959, *a*). The serpentine from amphibole and pyroxene commonly shows an analogous structure; the iron particles following the former cleavage lines. Hence the nature of the original mineral can often be inferred. Cf. Fig. 959, *a*, *b*, *c* (Pirsson).

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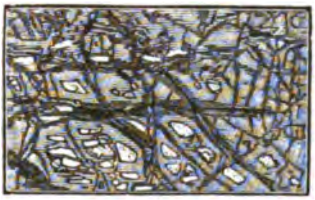


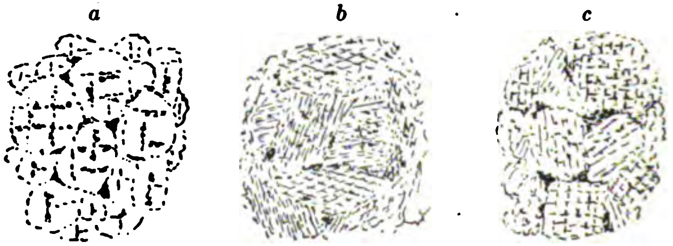
Comp. — A magnesium silicate, $H_4Mg_3Si_2O_9$ or $3MgO.2SiO_2.2H_2O$ = Silica 44.1, magnesia 43·0, water 12·9 = 100. Iron protoxide often replaces a small part of the magnesium; nickel in small amount is sometimes present. The water is chiefly expelled at a red heat.

Pyr., etc. — In the closed tube yields water. B.B. fuses on the edges with difficulty. F. = 6. Gives usually an iron reaction. Decomposed by hydrochloric and sulphuric acids. From chrysotile the silica is left in fine fibers.

Diff. — Characterized by softness, absence of cleavage and feeble waxy or oily luster; low specific gravity; by yielding much water B.B.

Micro. — Readily recognized in thin sections by its greenish or yellowish green color; low relief and aggregate polarization due to its fibrous structure. When the fibers are parallel, the interference-colors are not very low, but the confused aggregates may show the "ultra blue" or even be isotropic. The constant association with other magnesia bearing minerals like chrysolite, pyroxene, hornblende, etc., is also characteristic. The presence of lines of iron oxide particles as noted above (Fig. 959) is characteristic.

959



a, Serpentine derived from chrysolite; *b*, from amphibole; *c*, from pyroxene

Obs. — Serpentine is always a secondary mineral resulting, as noted above, from the alteration of silicates containing magnesia, particularly chrysolite, amphibole or pyroxene. It frequently forms large rock-masses, then being derived from the alteration of peridotites, dunites and other basic rocks of igneous origin; also of amphibolites, or pyroxene and chrysolite rocks of metamorphic origin. In the first case it is usually accompanied by spinel, garnet, chromite and sometimes nickel ores; in the second case by various carbonates such as dolomite, magnesite, breunnerite, etc.

Crystals of serpentine, pseudomorphous after monticellite, occur in the Fassatal, Tyrol, Austria. A variety containing soda from the Zillertal, Tyrol, is called *nemaphyllite*. Near Miask at Lake Aushkul, Barsovka, Ekaterinburg, and elsewhere in Russia; in Norway, at Snarum; etc. Fine precious serpentines come from Falun and Gulsjö in Sweden, the Isle of Man, the neighborhood of Portsoy in Aberdeenshire, Scotland; the Lizard in Cornwall, England; Corsica, Siberia, Saxony, etc.

In North America, in Me., at Deer Isle, precious serpentine. In Ver., at New Fane, Roxbury, etc. In Mass., fine at Newburyport. In R. I., at Newport; *bowenite* at Smithfield. In Conn., near New Haven and Milford, at the verd-antique quarries. In N. Y., at Port Henry, Essex Co.; at Antwerp, Jefferson Co., in crystals; in Gouverneur, St. Lawrence Co., in crystals; in Cornwall, Monroe, and Warwick, Orange Co., sometimes in large crystals at Warwick; and from Richmond to New Brighton, Richmond Co.; Brewsters. In N. J., at Hoboken, with brucite, magnesite, etc.; at Montville, Morris Co., chrysotile and retinalite, with common serpentine, produced by the alteration of pyroxene. In Pa., massive, fibrous, and foliated, at Texas, Lancaster Co.; at West Chester, Chester Co., *williamsite;* at Mineral Hill, Newtown, Marple, and Middletown, Delaware Co. In Md., at Bare Hills; at Cooptown, Harford Co., with diallage. In Cal., at various points in the Coast Range. Asbestus in notable deposits is found in the Grand Canyon, Ash Creek and Sierra Ancha Mts., Ariz.

In Canada, abundant among the metamorphic rocks of the Eastern Townships and Gaspé peninsula, Quebec; at Thetford, Coleraine, Broughton, Orford, South Ham, Bolton, Shipton, Melbourne, etc. The fibrous variety chrysotile (asbestus, bostonite) often forms seams several inches in thickness in the massive mineral, and is now extensively mined for technical purposes. Massive Laurentian serpentine also occurs in Grenville, Argenteuil Co., Quebec, and North Burgess, Lanark Co., Ontario. In New Brunswick, at Crow's Nest in Portland.

The names *Serpentine, Ophite, Lapis colubrinus,* allude to the green serpent-like cloudings of the serpentine marble. *Retinalite* is from ῥετινὴ, *resin; Picrolite,* from πικρός, *bitter,* in allusion to the magnesia (or Bittererde) present; *Thermophyllite,* from θέρμη, *heat,* and φύλλον, *leaf,* on account of the exfoliation when heated; *Chrysotile,* from χρυσος, *golden,* and τίλος, *fibrous; Metaxite,* from μέταξα, *silk; Marmolite,* from μαρμαίρω, *to shine,* in allusion to its peculiar luster.

Use. — As an ornamental stone; the fibrous variety furnishes the greater part of the heat insulating material known as asbestus.

Deweylite. A magnesian silicate near serpentine but with more water. Formula perhaps $4MgO.3SiO_2.6H_2O$. Amorphous, resembling gum arabic, or a resin. H. = 2–3·5. G. = 2·0–2·2. Color whitish, yellowish, reddish, brownish. Index, 1·55. Occurs with serpentine in the Fleimstal, Tyrol, Austria; also at Texas, Pa., and the Bare Hills, Md. *Gymnite* of Thomson, named from γυμνός, *naked,* in allusion to the locality at Bare Hills, Md., is the same species.

Genthite. Nickel Gymnite. A gymnite with part of the magnesium replaced by nickel, $2NiO.2MgO.3SiO_2.6H_2O$. Amorphous, with a delicate stalactitic surface, incrusting. H. = 3–4; sometimes very soft. G. = 2·409. Luster resinous. Color pale apple-green, or yellowish. From Texas, Lancaster Co., Pa., in thin crusts on chromite.

Nepouite. $3(Ni,Mg)O.2SiO_2.2H_2O$. In microscopic crystal plates with hexagonal outline. Good cleavages. H. = 2–2·5. G. = 2·5–3·2. Color pale to deep green. β = 1·62–1·63. Occurs in the nickel deposits of New Caledonia.

Garnierite. Noumeite. An important ore of nickel, consisting essentially of a hydrated silicate of magnesium and nickel, perhaps $H_2(Ni,Mg)SiO_4$ + water, but very variable in composition, particularly as regards the nickel and magnesium; not always homogeneous. Amorphous. Soft and friable. G. = 2·3–2·8. Luster dull. Color bright apple-green, pale green to nearly white. Index, 1·59. In part unctuous; sometimes adheres to the tongue. Occurs in serpentine rock near Noumea, capital of New Caledonia, associated with chromic iron and steatite, where it is extensively mined. A similar ore occurs at Riddle in Douglas County, southern Oregon; also at Webster, Jackson Co., N. C.

TALC.

Orthorhombic or monoclinic. Rarely in tabular crystals, hexagonal or rhombic with prismatic angle of 60°. Usually foliated massive; sometimes in globular and stellated groups; also granular massive, coarse or fine; fibrous (pseudomorphous); also compact or cryptocrystalline.

Cleavage: basal, perfect. Sectile. Flexible in thin laminæ, but not elastic. Percussion-figure a six-rayed star, oriented as with the micas. Feel greasy. H. = 1–1·5. G. = 2·7–2·8. Luster pearly on cleavage surface. Color apple-green to white, or silvery white; also greenish gray and dark green; sometimes bright green perpendicular to cleavage surface, and brown and less translucent at right angles to this direction; brownish to blackish-green and reddish when impure. Streak usually white; of dark green varieties lighter than the color. Subtransparent to translucent. Optically negative. Ax. pl. ∥ a (100). Bx ⊥ c (001). Axial angle small, variable. Indices approx.; $\alpha = 1·539$. $\beta = 1·589$. $\gamma = 1·589$.

Var. — *Foliated, Talc.* Consists of folia, usually easily separated, having a greasy feel and presenting ordinarily light green, greenish white, and white colors. G. = 2·55–2·78.

Massive, Steatite or *Soapstone.* *a.* Coarse granular, grayish green, and brownish gray in color; H. = 1–2·5. *Pot-stone* is ordinary soapstone, more or less impure. *b.* Fine granular or cryptocrystalline, and soft enough to be used as chalk; as the *French chalk*, which is milk-white with a pearly luster. *c. Indurated talc.* An impure slaty talc, harder than ordinary talc.

Pseudomorphous. *a.* Fibrous, fine to coarse, altered from enstatite and tremolite. *b. Rensselaerite*, having the form of pyroxene from northern New York and Canada.

Comp. — An acid metasilicate of magnesium, $H_2Mg_3(SiO_3)_4$ or $H_2O.3MgO.4SiO_2$ = Silica 63·5, magnesia 31·7, water 4·8 = 100. The water goes off only at a red heat. Nickel is sometimes present in small amount.

Pyr., etc. — In the closed tube B.B., when intensely ignited, most varieties yield water. In the platinum forceps whitens, exfoliates, and fuses with difficulty on the thin edges to a white enamel. Moistened with cobalt solution, assumes on ignition a pale red color. Not decomposed by acids. Rensselaerite is decomposed by concentrated sulphuric acid.

Diff. — Characterized by extreme softness, soapy feel; common foliated structure; pearly luster; it is flexible but inelastic. Yields water only on intense ignition.

Obs. — Talc or steatite is a very common mineral, and in the latter form constitutes extensive beds in some regions. It is often associated with serpentine, talcose or chloritic schist, and dolomite, and frequently contains crystals of dolomite, breunnerite, also asbestus, actinolite, tourmaline, magnetite.

Steatite is the material of many pseudomorphs, among which the most common are those after pyroxene, hornblende, mica, scapolite, and spinel. The magnesian minerals are those which commonly afford steatite by alteration; while those like scapolite and nephelite, which contain soda and no magnesia, most frequently yield pinite-like pseudomorphs. There are also steatitic pseudomorphs after quartz, dolomite, topaz, chiastolite, staurolite, cyanite, garnet, vesuvianite, chrysolite, gehlenite. Talc in the fibrous form is pseudomorph after enstatite and tremolite.

Apple-green talc occurs at Mt. Greiner in the Zillertal, Tyrol, Austria; in the Valais and St. Gothard in Switzerland; in Cornwall, England, near Lizard Point, with serpentine; the Shetland islands.

In North America, foliated talc occurs in Me., at Dexter. In Ver., at Bridgewater, handsome green talc, with dolomite; Newfane. In Mass., at Middlefield, Windsor, Blanford, Andover, and Chester. In R. I., at Smithfield, delicate green and white in a crystalline limestone. In N. Y., at Edwards, St. Lawrence Co., a fine fibrous talc (*agalite*) associated with pink tremolite; on Staten Island. In N. J., Sparta. In Pa., at Texas, Nottingham, Unionville; in South Mountain, ten miles south of Carlisle; at Chestnut Hill, on the Schuylkill, talc and also soapstone, the latter quarried extensively. In Md., at Cooptown, of green, blue, and rose colors. In N. C., at Webster, Jackson Co. The important states for the production of talc and soapstone are New York, Vermont and Virginia. In Canada, in the townships Bolton, Sutton, and Potton, Quebec, with steatite in beds of Cambrian age; in the township of Elzevir, Hastings Co., Ontario, an impure grayish variety in Archæan rocks.

Use. — In the form of soapstone used for wash tubs, sinks, table tops, switchboards, hearth stones, furnace linings, etc.; the tips of gas burners, tailors' chalk, slate pencils, carved ornaments, etc.; in powdered form as filler in papers, as a lubricant, in toilet powders, etc.

GAVITE is apparently a variety of talc, differing in the amount of water present and in its solubility in acids. From Gava valley, Italy.

SEPIOLITE. Meerschaum.

Compact, with a smooth feel, and fine earthy texture, or clay-like; also rarely fibrous. H. = 2–2·5. G. = 2. Impressible by the nail. In dry masses floats on water. Color grayish white, white, or with a faint yellowish or reddish tinge, bluish green. Opaque. Biaxial, –. β = 1·55.

Comp. — $H_4Mg_2Si_3O_{10}$ or $2H_2O.2MgO.3SiO_2$ = Silica 60·8, magnesia 27·1, water 12·1 = 100. Some analyses show more water, which is probably to be regarded as hygroscopic. Copper and nickel may replace part of the magnesium.

Pyr., etc. — In the closed tube yields first hygroscopic moisture, and at a higher temperature gives much water and a burnt smell. B.B. some varieties blacken, then burn white, and fuse with difficulty on the thin edges. With cobalt solution a pink color on ignition. Decomposed by hydrochloric acid with separation of silica.

Obs. — Occurs in Asia Minor, in masses in stratified earthy or alluvial deposits at the plains of Eskihi sher; at Hrubschitz in Moravia; in Morocco, called in French *Pierre de Savon de Maroc;* at Vallecas in Spain, in extensive beds.

A fibrous mineral, having the composition of sepiolite, occurs in Utah.

The word *meerschaum* is German for *sea-froth*, and alludes to its lightness and color. *Sepiolite* is from *σήπια*, *cuttle-fish*, the bone of which is light and porous.

Connarite. A hydrous nickel silicate, perhaps $H_4Ni_2Si_3O_{10}$. In small fragile grains. G. = 2·459–2·619. Color yellowish green. From Röttis, in Saxon Voigtland.

Spadaite. Perhaps $5MgO.6SiO_2.4H_2O$. Massive, amorphous. Color reddish. From Capo di Bove, near Rome.

SAPONITE. Piotine.

Massive. In nodules, or filling cavities. Soft, like butter or cheese, but brittle on drying. G. = 2·24–2·30. Luster greasy. Color white, yellowish, grayish green, bluish, reddish. Does not adhere to the tongue.

Comp. — A hydrous silicate of magnesium and aluminium; but the material is amorphous and probably always impure, and hence analyses give no uniform results. Contains SiO_2 40–45 p. c., Al_2O_3 5–10 p. c., MgO 19–26 p. c., H_2O 19–21 p. c.; also Fe_2O_3, FeO, etc.

Pyr., etc. — B.B. gives out water very readily and blackens; thin splinters fuse with difficulty on the edge. Decomposed by sulphuric acid.

Obs. — Occurs in cavities in basalt, diabase, etc.; also with serpentine. Thus at Lizard Point, Cornwall, in veins in serpentine; at various localities in Scotland, etc.

Saponite is from *sapo*, *soap;* and piotine from *πιότης*, *fat*.

LASSALLITE. Composition perhaps $3MgO.2Al_2O_3.12SiO_2.8H_2O$.. In snow-white fibrous masses. G. = 1.5. From the antimony mine at Miramont and at Can Pey near Arles-sur-Tech, France.

Celadonite. A silicate of iron, magnesium and potassium. Earthy or in minute scales. Very soft. Color green. Index, 1·63. From cavities in amygdaloid at Mte. Baldo near Verona, Italy.

Glauconite. Essentially a hydrous silicate of iron and potassium. Amorphous, and resembling earthy chlorite; either in cavities in rocks, or loosely granular massive. Color dull green. Index, 1·61. Occurs in rocks of nearly all geological ages; abundant in the "green sand," of the Chalk formation, sometimes constituting 75 to 90 p. c. of the whole. Found abundantly in ocean sediments near the continental shores. A manganese glauconite from the Marsjat forest, Ural Mts., has been called *marsjatskite*. *Greenalite* is a green hydrated ferrous silicate found as granules in the cherty rock associated with iron ores of the Mesabi district, Minn. Resembles glauconite but contains no potash.

Pholidolite. Corresponds approximately to $K_2O.12(Fe,Mg)O.Al_2O_3.13SiO_2.5H_2O$. In minute crystalline scales. G. = 2·408. Color grayish yellow. From Taberg in Wermland, Sweden, with garnet, diopside, etc.

IV. KAOLIN DIVISION

KAOLINITE. Kaolin.

Monoclinic; in thin rhombic, rhomboidal or hexagonal scales or plates with angles of 60° and 120°. Usually constituting a clay-like mass, either compact, friable or mealy.

Cleavage: basal, perfect. Flexible, inelastic. H. = 2–2·5. G. = 2·6–2·63. Luster of plates, pearly; of mass, pearly to dull earthy. Color white, grayish white, yellowish, sometimes brownish, bluish or reddish. Scales transparent to translucent; usually unctuous and plastic.

Optically biaxial, negative. $Bx_o \perp b$ (010). Bx_a and ax. pl. inclined behind some 20° to normal to c (001). Axial angle large, approx. 90°. $\beta = 1{\cdot}482$.

Var. — 1. *Kaolinite.* In crystalline scales, pure white and with a satin luster in the mass. 2. *Ordinary.* Common kaolin, in part in crystalline scales but more or less impure including the compact *lithomarge.*

Comp. — $H_4Al_2Si_2O_9$, or $2H_2O.Al_2O_3.2SiO_2$ = Silica 46.5, alumina 39.5, water 14·0 = 100. The water goes off at a high temperature, above 330°.

Pyr., etc. — Yields water. B.B. infusible. Gives a blue color on ignition with cobalt solution. Insoluble in acids.

Diff. — Characterized by unctuous, soapy feel and the alumina reaction B.B. Resembles infusorial earth, but readily distinguished under the microscope.

Obs. — Ordinary kaolin is a result of the decomposition of aluminous minerals, especially the feldspar of granitic and gneissoid rocks and porphyries. In some regions where these rocks have decomposed on a large scale, the resulting clay remains in vast beds of *kaolin,* usually more or less mixed with free quartz, and sometimes with oxide of iron from some of the other minerals present. Pure kaolinite in scales often occurs in connection with iron ores of the Coal formation. It sometimes forms extensive beds in the Tertiary formation, as near Richmond, Va. Also met with accompanying diaspore and emery or corundum.

Occurs in the coal formation in Belgium; Schlan in Bohemia; in argillaceous schist at Lodève, Dept. of Hérault, France; as kaolin at Diendorf (Bodenmais) in Bavaria; at Schemnitz, Hungary; with fluorite at Zinnwald, Germany. Yrieix, near Limoges, France, is the best locality of kaolin in Europe (a discovery of 1765); it affords material for the famous Sèvres porcelain manufactory. Large quantities of clay (kaolin) are found in Cornwall and West Devon, England.

In the United States, kaolin occurs at Newcastle and Wilmington, Del.; at various localities in the limonite region of Ver. (at Brandon, etc.), Mass., Delaware Co., Pa.; Jacksonville, Ala.; near Webster, N. C.; Edgefield, S. C.; near Augusta, Ga. In crystal plates from National Belle mine, Silverton, Col. From Lawrence Co., Ind.

The name *Kaolin* is a corruption of the Chinese *Kauling,* meaning *high-ridge,* the name of a hill near Jauchau Fu, where the material is obtained.

Use. — The finer, purer grades used in the manufacture of porcelain, china, etc.; in the form of clay in pottery, stoneware, bricks, etc.

Pholerite. Near kaolinite, but some analyses give 15 p. c. water. The original was from the coal mines of Fins, Dept. of Allier, France.

Faratsihite. $(Al,Fe)_2O_3.2SiO_2.2H_2O$. Intermediate between *kaolinite* and *chloropal.* Monoclinic. In microscopic hexagonal plates. Soft. G. = 2. Color pale yellow. Index a little higher than that of kaolinite. Difficultly fusible. Decomposed by hydrochloric acid. From Faratsiho, Madagascar.

HALLOYSITE.

Massive. Clay-like or earthy.

Fracture conchoidal. Hardly plastic. H. = 1–2. G. = 2·0–2·20. Luster somewhat pearly, or waxy, to dull. Color white, grayish, greenish, yellowish, bluish, reddish. Translucent to opaque, sometimes becoming translucent or even transparent in water, with an increase of one-fifth in weight.

Var. — *Ordinary.* Earthy or waxy in luster and opaque massive. *Galapectite* is halloysite of Angleur, Belgium. *Pseudosteatite* is an impure variety, dark green in color, with H. = 2·25. G. = 2·469. *Indianaite* is a white porcelain clay from Lawrence Co., Indiana, where it occurs with allophane in beds four to ten feet thick.

Smectite is greenish, and in certain states of humidity appears transparent and almost gelatinous; it is from Condé, near Houdan, France.

Bole, in part, may belong here; that is those colored, unctuous clays containing more or less iron oxide, which also have about 24 p. c. of water; the iron gives them a brownish, yellowish or reddish color; but they may be mixtures. Here belongs *Bergseife* (mountain-soap).

Comp. — A silicate of aluminium ($Al_2O_3.2SiO_2$) like kaolinite, but amorphous and containing more water; the amount is somewhat uncertain, but the formula is probably to be taken as $H_4Al_2Si_2O_9.H_2O$ or $2H_2O.Al_2O_3.2SiO_2.H_2O$ = Silica 43·5, alumina 36·9, water 19·6 = 100.

Pyr., etc. — Yields water. B.B. infusible. A fine blue on ignition with cobalt solution. Decomposed by acids.

Obs. — Occurs often in veins or beds of ore, as a secondary product; also in granite and other rocks, being derived from the decomposition of some aluminous minerals.

TERMIERITE. A clay-like substance resembling halloysite of uncertain composition from the antimony mines of Miramont, France.

Newtonite. $H_8Al_2Si_2O_{11}.H_2O$. In soft white compact masses resembling kaolin. Found on Sneed's Creek in the northern part of Newton Co., Ark.

BATCHELORITE. $Al_2O_3.2SiO_2.H_2O$. A green foliated mineral from Mt. Lyell mine, Tasmania.

Cimolite. A hydrous silicate of aluminium, $2Al_2O_3.9SiO_2.6H_2O$. Amorphous clay-like, or chalky. Very soft. G. = 2·18–2·30. Color white, grayish white, reddish. From the island of Argentiera (Kimolos of the Greeks).

Montmorillonite. Probably $H_2Al_2Si_4O_{12}.nH_2O$. Massive, clay-like. Very soft and tender. Luster feeble. Color white or grayish to rose-red, and bluish; also pistachio-green. Unctuous. *Montmorillonite,* from Montmorillon, France, is rose-red. *Confolensite* is paler rose-red; from Confolens, Dept. of Charente at St. Jean-de-Cole, near Thiviers.

Stolpenite is a clay from the basalt of Stolpen, Germany. *Saponite* of Nicklès is a white, plastic, soap-like clay from the granite from which issues one of the hot springs of Plombières, France, called *Soap Spring;* it was named *smegmatite* by Naumann.

PYROPHYLLITE.

Monoclinic? Foliated, radiated lamellar or somewhat fibrous; also granular to compact or cryptocrystalline; the latter sometimes slaty.

Cleavage: basal, eminent. Laminæ flexible, not elastic. Feel greasy. H. = 1–2. G. = 2·8–2·9. Luster of folia pearly; of massive kinds dull and glistening. Color white, apple-green, grayish and brownish green, yellowish to ocher-yellow, grayish white. Subtransparent to opaque. Optically —. Bx ⊥ cleavage. Ax. angle large, to 108°. Mean index, 1·58.

Var. — (1) *Foliated,* and often radiated, closely resembling talc in color, feel, luster and structure. (2) *Compact massive,* white, grayish and greenish, somewhat resembling compact steatite, or French chalk. This compact variety includes part of what has gone under the name of agalmatolite, from China; it is used for slate-pencils, and is sometimes called *pencil-stone.*

Comp. — $H_2Al_2(SiO_3)_4$ or $H_2O.Al_2O_3.4SiO_2$ = Silica 66·7, alumina 28·3, water 5·0 = 100.

Pyr., etc. — Yields water, but only at a high temperature. B.B. whitens, and fuses with difficulty on the edges. The radiated varieties exfoliate in fan-like forms, swelling up to many times the original volume of the assay. Moistened with cobalt solution and heated gives a deep blue color (alumina). Partially decomposed by sulphuric acid, and completely on fusion with alkaline carbonates.

Diff. — Resembles some talc, but distinguished by the reaction for alumina with cobalt solution.

Obs. — Compact pyrophyllite is the material or base of some schistose rocks. The foliated variety is often the gangue of cyanite. Occurs in the Ural Mts.; at Westanå, Sweden; near Ottrez, Luxemburg; Ouro Preto, Brazil.

Also in white stellate aggregations in Cottonstone Mt., Mecklenburg Co., N. C.; in Chesterfield Dist., S. C., with lazulite and cyanite; in Lincoln Co., Ga., on Graves Mt. The compact kind, at Deep River, N. C., is extensively used for making slate-pencils and resembles the so-called agalmatolite or pagodite of China, often used for ornamental carvings.

Use. — For the same purposes as talc, which see.

ALLOPHANE.

Amorphous. In incrustations, usually thin, with a mammillary surface, and hyalite-like; sometimes stalactitic. Occasionally almost pulverulent.

Fracture imperfectly conchoidal and shining, to earthy. Very brittle. H. = 3. G. = 1·85–1·89. Luster vitreous to subresinous; bright and waxy internally. Color pale sky-blue, sometimes greenish to deep green, brown, yellow or colorless. Streak uncolored. Translucent. n = 1·49.

Comp. — Hydrous aluminium silicate, $Al_2SiO_5.5H_2O$ = Silica 23·8, alumina 40·5, water 35·7 = 100. Some analyses give 6 equivalents of water = Silica 22·2, alumina 37·8, water 40·0 = 100.

Impurities are often present. The coloring matter of the blue variety is due to traces of chrysocolla, and substances intermediate between allophane and chrysocolla (mixtures) are not uncommon. The green variety is colored by malachite, and the yellowish and brown by iron.

Pyr., etc. — Yields much water in the closed tube. B.B. crumbles but is infusible. Gives a blue color on ignition with cobalt solution. Gelatinizes with hydrochloric acid.

Obs. — Allophane is regarded as a result of the decomposition of some aluminous silicate (feldspar, etc.); and it often occurs incrusting fissures or cavities in mines, especially those of copper and limonite, and even in beds of coal.

Named from *αλλος, other*, and *φαίνεσθαι, to appear*, in allusion to its change of appearance under the blowpipe.

Melite. $2(Al,Fe)_2O_3.SiO_2.8H_2O$. In imperfect prisms. Stalactitic, massive. H. = 3. G. = 2·2. Color bluish brown. Infusible. From Saalfield, Thuringia.

Collyrite. $2Al_2O_3.SiO_2.9H_2O$. A clay-like mineral, white, with a glimmering luster, greasy feel, and adhering to the tongue. G. = 2–2·15. From Ezquerra in the Pyrenees.

Schrötterite. $8Al_2O_3.3SiO_2.30H_2O$. Resembles allophane; sometimes like gum in appearance. H. = 3–3·5. G. = 1·95–2·05. Color pale green or yellowish. From Dollinger mountain, near Freienstein, in Styria; at the Falls of Little River, on the Sand Mt., Cherokee Co., Ala.

The following are clay-like minerals or mineral substances: *Sinopite, smectite, catlinite.*

Cenosite. $H_4Ca_2(Y,Er)_2CSi_4O_{17}$. Orthorhombic. G. = 3·38. Color yellowish brown. From Hitterö, Norway; Nordmark, Sweden.

Britholite. A complex silicate and phosphate of the cerium metals and calcium. Hexagonal. In minute crystals. H. = 5·5. G. = 4·4. Color brown. From nepheline syenite region of Julianehaab, South Greenland.

Erikite. Composition uncertain: essentially a silicate and phosphate of the cerium metals. Orthorhombic. In prismatic crystals. H. = 5·5. G. = 3·5. Color light yellow-brown to dark gray-brown. From nepheline-syenite in South Greenland.

Plazolite. $3CaO.Al_2O_3.2(SiO_2,CO_2).2H_2O$. Isometric. In minute dodecahedrons. H. = 6·5. G. = 3·13. Colorless to light yellow. n = 1·71. From Crestmore, Cal.

Thaumasite. $CaSiO_3.CaCO_3.CaSO_4.15H_2O$. Massive, compact, crystalline. Cleavage in traces. H. = 3·5. G. = 1·877. Color white. Uniaxial, −. ω = 1·507. ϵ = 1·468. Occurs filling cavities and crevices at the Bjelke mine, near Åreskuta, Jemtland, Sweden; at first soft but hardens on exposure to the air. Also in fibrous crystalline masses at Paterson, N. J.; from Beaver Co., Utah.

Spurrite. $2Ca_2SiO_4.CaCO_3$. Probably monoclinic. In granular cleavable masses. H. = 5. Color pale gray. β = 1·67. Infusible. From contact zone between limestone and diorite in Velardeña mining district, Mexico.

Uranophane. Uranotil. $CaO.2UO_3.2SiO_2.6H_2O$. In radiated aggregations; massive, fibrous. G. = 3·81–3·90. Color yellow. Biaxial, −. Indices, 1·650–1·670. From the granite of Kupferberg, Silesia. *Uranotil* occurs at Wölsendorf, Bavaria; Mitchell Co., N. C.

Dixenite. $MnSiO_3.2Mn_2(OH)AsO_3$. Hexagonal. In aggregates of thin folia. H. = 3–4. Basal cleavage. Color nearly black, red by transmitted light. Optically +. n = 1·96. From Långban, Sweden.

Bakerite. A hydrated calcium borosilicate, $8CaO.5B_2O_3.6SiO_2.6H_2O$. In compact masses resembling unglazed porcelain. H. = 4·5. G. = 2·7–2·9. Color white. Fusible. From borax deposits in Mohave desert, 16 miles N. E. of Daggett, San Bernardino Co., Cal.

CHRYSOCOLLA.

Cryptocrystalline; often opal-like or enamel-like in texture; earthy. Incrusting or filling seams. Sometimes botryoidal. In microscopic acicular crystals from Mackay, Idaho.

Fracture conchoidal. Rather sectile; translucent varieties brittle. H. = 2–4. G. = 2–2·238. Luster vitreous, shining, earthy. Color mountain-green, bluish green, passing into sky-blue and turquois-blue; brown to black when impure. Streak, when pure, white. Translucent to opaque. Crystals from Idaho gave: Uniaxial, +; ω = 1·46; ϵ = 1·57; weakly pleochroic, ω = colorless, ϵ = pale blue-green.

Comp. — True chrysocolla appears to correspond to $CuSiO_3.2H_2O$ = Silica 34·3, copper oxide 45·2, water 20·5 = 100, the water being double that of dioptase.

Composition varies much through impurities; free silica, also alumina, black oxide of copper, oxide of iron (or limonite) and oxide of manganese may be present; the color consequently varies from bluish green to brown and black. It has been suggested that the composition of most chrysocolla is not definite but that it is usually in the form of a mineral gel with copper oxide, silica and water occurring in varying proportions according to the conditions of formation.

Pyr., etc. — In the closed tube blackens and yields water. B.B. decrepitates, colors the flame emerald-green, but is infusible. With the fluxes gives the reactions for copper. With soda and charcoal a globule of metallic copper. Decomposed by acids without gelatinization.

Obs. — Accompanies other copper ores, occurring especially in the upper part of veins. Found in copper mines in Cornwall, England; Hungary; Siberia; Saxony; South Australia; Chile, etc.

In the United States, similarly at the Schuyler's mines, N. J.; at Morgantown, Pa.; at the Clifton mines, Graham Co., in Gila Co., Ariz.; Emma mine, Utah. In crystals from Mackay, Idaho.

Chrysocolla is from *χρυσος*, *gold*, and *κόλλα*, *glue*, and was the name of a material used in soldering gold. The name is often applied now to borax, which is so employed.

Use. — Chrysocolla may serve as a minor ore of copper.

Shattuckite. $2CuSiO_3.H_2O$. Compact, granular, fibrous. G. = 3·8. Color blue. Indices, 1·73–1·80. Pleochroic, dark to light blue. Found at Shattuck mine, Bisbee, Ariz., forming pseudomorphs after *malachite*.

Bisbeeite. $CuSiO_3.H_2O$. Orthorhombic, fibrous. Color pale blue to nearly white; Elongation of fibers positive. Indices 1·59 to 1·65. Pleochroic, very pale green to pale olive-brown. Found at Shattuck mine at Bisbee, Ariz., resulting from the hydration of *shattuckite*.

CHLOROPAL.

Compact massive, with an opal-like appearance; earthy.

H. = 2·5–4·5. G. = 1·727–1·870, earthy varieties, the second a conchoidal specimen; 2·105, Ceylon. Color greenish yellow and pistachio-green. Opaque to subtranslucent. Fragile. Fracture conchoidal and splintery to earthy. Adheres feebly to the tongue.

Var. — *Chloropal* has the above-mentioned characters, and was named from the Hungarian mineral occurring at Unghwar.

Nontronite is pale straw-yellow or canary-yellow, and greenish, with an unctuous feel; flattens and grows lumpy under the pestle, and is polished by friction; from Nontron, Dept. of Dordogne, France. *Pinguite* is siskin- and oil-green, extremely soft, like new-made soap, with a slightly resinous luster, not adhering to the tongue; from Wolkenstein in Saxony. *Graminite* has a grass-green color (whence the name), and occurs at Menzenberg, in the Siebengebirge, Germany; in thin fibrous seams, or as delicate lamellæ.

Comp. — A hydrated silicate of ferric iron, perhaps with the general formula $H_6Fe_2(SiO_4)_3.2H_2O$ or $Fe_2O_3.3SiO_2.5H_2O$ = Silica 41·9, iron sesquioxide 37·2, water 20·9 = 100. Alumina is present in some varieties.

The water and silica both vary much. The Hungarian chloropal occurs mixed with opal, and graduates into it, and this accounts for the high silica of some of its analyses.

Obs. — Localities mentioned above. *Chloropal* occurs also at Meenser Steinberg near Göttingen, Germany; *pinguite* at Sternberg, Moravia. On Lehigh Mt., Pa., south of Allentown, occurs in connection with iron deposits. From Palmetto Mts., Esmeralda Co., Nev.

Hœferite. An iron silicate near chloropal. Color green. From Křitz, Bohemia.

Müllerite. *Zamboninite.* $Fe_2Si_3O_9.2H_2O$. Massive. Resembles nontronite. Soft. G. = 2·0. Color yellowish green. Infusible. From Nontron, Dordogne, France.

Hisingerite. A hydrated ferric silicate, of uncertain composition. Amorphous, compact. Fracture conchoidal. H. = 3. G. = 2·5–3·0. Luster greasy. Color black to brownish black. Streak yellowish brown. From Riddarhyttan, Tunaberg, Sweden; Långban, etc., Norway; from Greenland.

Morencite. A hydrated ferric silicate of uncertain composition. Fibrous. Color brownish yellow. From Morenci, Ariz.

The following are hydrous manganese silicates.

Bementite. $H_6Mn_5(SiO_4)_4$. Orthorhombic. Cleavages || to three pinacoids. In soft radiated masses resembling pyrophyllite. G. = 2·981. Color pale grayish yellow. From the zinc mines of Franklin Furnace, N. J.

Ectropite. $Mn_2Si_8O_{28}.7H_2O$. Monoclinic(?). In thin tabular crystals. Good cleavage. H. = 4. G. = 2·46. Color brown. Opaque. Indices, 1·62–1·63. From Långban, Sweden.

Agnolite. $H_2Mn_3(SiO_3)_4.H_2O$. Name given to the manganese silicate occurring as part of the material from Schemnitz, Hungary, known as *manganocalcite.* Triclinic. In radiating fibrous masses. Color flesh-red to rose. H. = 5. G. = 3·0.

Orientite. $Ca_4\overset{III}{Mn}_4(SiO_4)_5.4H_2O$. Orthorhombic. Radiating prismatic. Brown to black. Transparent to opaque. H. = 4·5–5. G. = 3. Optically +. $\alpha = 1·758$. $\beta = 1·776$. $\gamma = 1·795$. From Oriente Province, Cuba.

Hodgkinsonite. $3(Zn,Mn)O.SiO_2.H_2O$. Monoclinic. In acute pyramidal crystals. Perfect basal cleavage. H. = 4·5–5. G. = 3·91. Color, bright pink to reddish brown. $n = 1·73$. Decrepitates and then fuses readily. Soluble in acids. From Franklin, N. J.

Gageite. — A hydrous silicate of manganese, magnesium and zinc, $8RO.3SiO_2.2H_2O$. In radiating groups of needle-like crystals. Colorless and transparent. From Franklin, N. J.

Caryopilite. Approximately $4MnO.3SiO_2.3H_2O$. In stalactitic and reniform shapes. G. = 2·83–2·91. Color brown. From the Harstig mine near Pajsberg, Sweden.

Neotocite. A hydrated silicate of manganese and iron, of doubtful composition, usually derived from the alteration of rhodonite. Amorphous. Color black to dark brown and liver-brown.

Searlesite. $NaB(SiO_3)_2.H_2O$. Monoclinic (?). In minute spherulites composed of radiating fibers. Color white. Indices, 1·52–1·53. Fusible. Decomposed by hydrochloric acid. Found at Searles Lake, San Bernardino Co., Cal.

Colerainite. $4MgO.Al_2O_3.2SiO_2.5H_2O$. Hexagonal. In minute, thin, hexagonal plates. H. = 2·5–3. G. = 2·51. Colorless or white. Optically +. Index, 1·56. Found in Black Lake area, Coleraine township, Quebec.

TARTARKAITE. A complex hydrous silicate of aluminium, magnesium, etc. Tabular crystals. G. = 2·7. Color dark gray to black. Uniaxial, +. In limestone on the Tartarka river, Yeniseï District, Siberia.

ITANO-SILICATES, TITANATES

This section includes the common calcium titano-silicate, Titanite; also a number of silicates which contain titanium, but whose relations are not altogether clear; further the titanate, Perovskite, and niobo-titanate, Dysanalyte, which is intermediate between Perovskite and the species Pyrochlore, Microlite, Koppite of the following section.

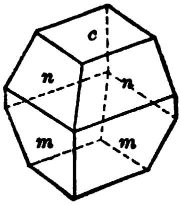
In general the part played by titanium in the many silicates in which it enters is more or less uncertain. It is probably in most cases, as shown in the preceding pages, to be taken as replacing the silicon; in others, however, it seems to play the part of a basic element; in schorlomite (p. 510) it may enter in both relations.

TITANITE. Sphene.

Monoclinic. Axes $a : b : c = 0·7547 : 1 : 0·8543$; $\beta = 60° 17'$.

mm''',	$110 \wedge 1\bar{1}0$	= 66° 29′.	*ll'*,	$\bar{1}12 \wedge \bar{1}\bar{1}2$	= 46° 7½′.
cx,	$001 \wedge 102$	= 21° 0′.	*cn*,	$001 \wedge 111$	= 38° 16′.
ss',	$021 \wedge 0\bar{2}1$	= 112° 3′.	*cm*,	$001 \wedge 110$	= 65° 30′.
nn',	$111 \wedge 1\bar{1}1$	= 43° 49′.	*cl*,	$001 \wedge \bar{1}12$	= 40° 34′.

960



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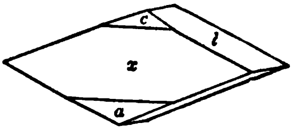

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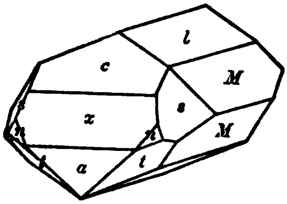

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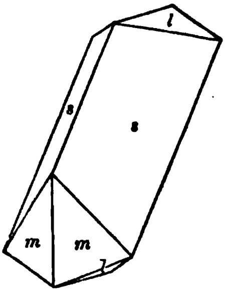

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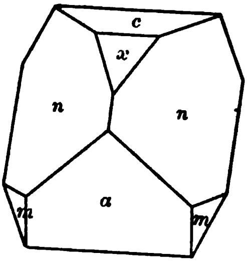

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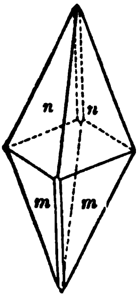

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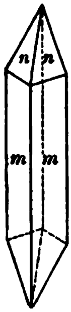


Twins: tw. pl. *a* (100) rather common, both contact-twins and cruciform penetration-twins. Crystals very varied in habit; often wedge-shaped and flattened || *c* (001); also prismatic. Sometimes massive, compact; rarely lamellar.

Cleavage: *m* (110) rather distinct; *a* (100), *l* ($\bar{1}$12) imperfect; in greenovite, *n* (111) easy, *t* ($\bar{1}$11) less so. Parting often easy || *η* (221) due to twinning lamellæ. H. = 5–5·5. G. = 3·4–3·56. Luster adamantine to resinous. Color brown, gray, yellow, green, rose-red and black. Streak white, slightly reddish in greenovite. Transparent to opaque.

Pleochroism in general rather feeble, but distinct in deep-colored kinds: *Z*, red with tinge of yellow; *Y*, yellow, often greenish; *X*, nearly colorless. Optically + . Ax. pl. || *b* (010). Bx nearly ⊥ *x* (102), *i.e.*, Bx $\wedge$ *c* axis = + 51°. Dispersion $\rho > v$ very large, and hence the peculiarity of the axial interference-figure in white light. Axial angles variable. 2V = 27°. α = 1·900. β = 1·907. γ = 2·034.

Var. — *Ordinary.* (*a*) *Titanite;* brown to black, the original being thus colored, also opaque or subtranslucent. (*b*) *Sphene* (named from *σφήν, a wedge*); of light shades, as yellow, greenish, etc., and often translucent; the original was yellow. *Ligurite* is an apple-green sphene. *Spinthere* (or Semeline) a greenish kind. *Lederite* is brown, opaque, or subtranslucent, of the form in Fig. 960.

Titanomorphite is a white mostly granular alteration-product of rutile and ilmenite, not uncommon in certain crystalline rocks; here also belongs most leucoxene (see p. 418).

Manganesian; Greenovite. Red or rose-colored, owing to the presence of a little manganese; from St. Marcel, Piedmont, Italy; from Jothvád in Nárukot, India.

Containing yttrium or cerium. Here belong *grothite, alshedite, eucolite-titanite.*

Comp. — $CaTiSiO_5$ or $CaO.TiO_2.SiO_2$ = Silica 30·6, titanium dioxide 40·8, lime 28·6 = 100. Iron is present in varying amounts, sometimes manganese and also yttrium in some kinds.

Pyr., etc. — B.B. some varieties change color, becoming yellow, and fuse at 3 with intumescence, to a yellow, brown or black glass. With borax they afford a clear yellowish green glass. Imperfectly soluble in heated hydrochloric acid; and if the solution be concentrated along with tin, it assumes a fine violet color. With salt of phosphorus in R. F. gives a violet bead; varieties containing much iron require to be treated with the flux on charcoal with metallic tin. Completely decomposed by sulphuric and hydrofluoric acids.

Diff. — Characterized by its oblique crystallization, a wedge-shaped form common; by resinous (or adamantine) luster; hardness less than that of staurolite and greater than that of sphalerite. The reaction for titanium is distinctive, but less so in varieties containing much iron.

Micro. — Distinguished in thin sections by its acute-angled form, often lozenge-shaped; its generally pale brown tone; very high relief and remarkable birefringence, causing the section to show white of the higher order; by its biaxial character (showing many lemniscate curves); and by its great dispersion, which produces colored hyperbolas.

Artif. — Titanite is apparently produced artificially only with difficulty. It has been obtained by fusing together silica and titanic oxide with calcium chloride.

Obs. — Titanite, as an accessory component, is widespread as a rock forming mineral, though confined mostly to the acidic feldspathic igneous rocks; it is much more common in the plutonic granular types than in the volcanic forms. Thus it is found in the more basic hornblende granites, syenites, and diorites, and is especially common and characteristic in the nephelite-syenites. It occurs also in the metamorphic rocks and especially in the schists, gneisses, etc., rich in magnesia and iron and in certain granular limestones. It is also found in beds of iron ore; commonly associated minerals are pyroxene, amphibole, chlorite, scapolite, zircon, apatite, etc. In cavities in gneiss and granite, it often accompanies adularia, smoky quartz, apatite, chlorite, etc.

Occurs at various points in the Grisons, Switzerland, associated with feldspar and chlorite; Tavetsch; Binnental; in the St. Gothard region; Zermatt in the Valais; Maderanertal in Uri; also elsewhere in the Alps; in Dauphiné (*spinthère*), France; in Italy at Ala (*ligurite*) and at St. Marcel, in Piedmont; at Schwarzenstein and Rothenkopf in the Zillertal, Pfitsch, Tyrol; Zöptau, Moravia; near Tavistock, England; near Tremadoc, in North Wales; from Kragerö and in titanic iron at Arendal, Norway; with magnetite at

Nordmark, Sweden; Achmatovsk, Ural Mts. Occasionally found among volcanic rocks, as at Lake Laach (*semeline*) and at Andernach on the Rhine.

In Me., in fine crystals at Sandford. In Mass., in gneiss, in the east part of Lee; at Bolton with pyroxene and scapolite in limestone. In N. Y., at Roger's Rock on Lake George, abundant in small brown crystals; at Gouverneur, in black crystals in granular limestone; in Diana near Natural Bridge, Lewis Co., in large dark brown crystals, among which is the variety *lederite;* at Rossie, Fine, Pitcairn, St. Lawrence Co.; in Orange Co., in limestone; near Edenville, in light brown crystals in limestone; at Brewster, at the Tilly Foster iron mine. In N. J., at Franklin Furnace, honey-yellow. In Pa., Bucks Co. three miles west of Attleboro', associated with wollastonite and graphite. In N. C., at Statesville, Iredell Co., yellowish white with sunstone; also Buncombe Co., Alexander Co., and other points.

Occurs in Canada in Quebec at Grenville, Argenteuil Co.; also Buckingham, Templeton, Wakefield, Hull, Ottawa Co.; in Ontario at North Burgess, honey-yellow; near Eganville, Renfrew Co., in very large dark brown crystals with apatite, amphibole, zircon.

Molengraaffite. A titano-silicate of lime and soda. Monoclinic(?). In imperfect prismatic crystals. Cleavage (100) perfect. Color yellow-brown. Indices, 1·73–1·77. From a rock, "lujaurite," in Pilandsberg, near Rustenberg, Transvaal.

Keilhauite. A titano-silicate of calcium, aluminium, ferric iron, and the yttrium metals. Crystals near titanite in habit and angles. H. = 6·5. G. = 3·52–3·77. Color brownish black. From near Arendal, Norway.

Tscheffkinite. A titano-silicate of the cerium metals, iron, etc., but an alteration product, more or less heterogeneous, and the composition of the original mineral is very uncertain. Massive, amorphous. H. = 5–5·5. G. = 4·508–4·549. Color velvet-black. From the Ilmen mountains in the Ural Mts. Also from South India, Kanjamalai Hill, Salem district. An isolated mass weighing 20 lbs. has been found on Hat Creek, near Massie's Mills, Nelson Co., Va.; also found, south of this point, in Bedford Co.

Astrophyllite. Probably $\overset{\text{I}}{R}_4\overset{\text{II}}{R}_4Ti(SiO_4)_4$ with $\overset{\text{I}}{R}$ = H, Na, K, and $\overset{\text{II}}{R}$ = Fe, Mn chiefly, including also Fe_2O_3. Orthorhombic. In elongated crystals; also in thin strips or blades; sometimes in stellate groups. Cleavage: *b* (010) perfect like mica, but laminæ brittle. H. = 3. G. = 3·3–3·4. Luster submetallic, pearly. Color bronze-yellow to gold-yellow. Optically +. Indices, 1·678–1·733.

Occurs on the small islands in the Langesund fiord, near Brevik, Norway, in elæolite-syenite, embedded in feldspar, with catapleiite, ægirite, black mica, etc. Similarly at Kangerdluarsuk and Narsarsuk, Greenland. Also with arfvedsonite and zircon at St. Peter's Dome, Pike's Peak, El Paso Co., Col.

Johnstrupite. A silicate of the cerium metals, calcium and sodium chiefly, with titanium and fluorine. In prismatic monoclinic crystals. G. = 3·29. Color brownish green. Index, 1·646. From near Barkevik, Norway.

Mosandrite. Near johnstrupite in form and composition and from the same region.

Rinkite, also near johnstrupite, is from Greenland.

Narsarsukite. A highly acidic titano-silicate of ferric iron and sodium. Tetragonal. In tabular crystals. Fine prismatic cleavage. H. = 7. G. = 2·7. Color honey-yellow, on weathering brownish gray or ocher-yellow. ω = 1·55. Fusible. In pegmatite at Narsarsuk, southern Greenland.

Neptunite. A titano-silicate of iron (manganese) and the alkali metals. In prismatic monoclinic crystals. H. = 5–6. G. = 3·23. Color black. Streak, cinnamon-brown. Mean index, 1·70. Pleochroic, yellow to deep-red. Found at Narsarsuk and elsewhere, southern Greenland, and at the benitoite locality in San Benito Co., Cal. (originally called *carlosite*).

Benitoite. $BaTiSi_3O_9$. Hexagonal, trigonal (ditrigonal-bipyramidal). In crystals with $\rho(10\bar{1}1)$ prominent. H. = 6·2–6·5. G. = 3·6. Color sapphire-blue to light blue and colorless. Transparent. Strongly dichroic, deep blue to colorless. ω = 1·77. Fusible at 3. Found associated with *neptunite* and *natrolite* near the headwaters of the San Benito River in San Benito Co., Cal.

Leucosphenite. $Na_4Ba(TiO)_2(Si_2O_5)_5$. Monoclinic. In minute wedge-shaped crystals. Distinct cleavage. H. = 6·5. G. = 3·0. Color white. β = 1·66. Difficultly fusible. From Narsarsuk, southern Greenland.

Lorenzenite. $Na_2(TiO)_2Si_2O_7$. Contains considerable zirconia. Orthorhombic. In minute acicular crystals. Distinct cleavage. H. = 6. G. = 3·4. β about 1·78. Fusible. From Narsarsuk, southern Greenland.

Joaquinite. A titano-silicate of calcium and iron. Orthorhombic. Color, honey-yellow. Associated with *benitoite* from San Benito Co., Cal.

PEROVSKITE. Perofskite.

Isometric or pseudo-isometric. Crystals in general (Ural Mts., Zermatt, Switzerland) cubic in habit and often highly modified, but the faces often irregularly distributed. Cubic faces striated parallel to the edges and apparently penetration-twins, as if of pyritohedral individuals. Also in reniform masses showing small cubes.

Cleavage: cubic, rather perfect. Fracture uneven to subconchoidal. Brittle. H. = 5·5. G. = 4·017–4·039. Luster adamantine to metallic-adamantine. Color pale yellow, honey-yellow, orange-yellow, reddish brown, grayish black. Streak colorless, grayish. Transparent to opaque. Usually exhibits anomalous double refraction. Mean index, about 2·38.

Geometrically considered, perovskite conforms to the isometric system; optically, however, it is uniformly biaxial and usually positive. The molecular structure (also as developed by etching) seems to correspond to orthorhombic symmetry. Cf. Art. 429.

Comp. — Calcium titanate, $CaTiO_3$ = Titanium dioxide 58·9, lime 41·1 = 100. Iron is present in small amount replacing the calcium.

Pyr., etc. — In the forceps and on charcoal infusible. With salt of phosphorus in O.F. dissolves easily, giving a greenish bead while hot, which becomes colorless on cooling; in R.F. the bead changes to grayish green, and on cooling assumes a violet-blue color. Entirely decomposed by boiling sulphuric acid.

Obs. — Occurs in small crystals, associated with chlorite, and magnetic iron in chlorite slate, at Achmatovsk, near Zlatoust, in the Ural Mts.; at Schelingen in the Kaiserstuhl, Germany, in granular limestone; in the valley of Zermatt, Switzerland, near the Findelen glacier; at Wildkreuzjoch, between Pfitsch and Pfunders in Tyrol, Austria; various localities, Piedmont, Italy. Sometimes noted in microscopic octahedral crystals as a rock constituent; thus in nephelite- and melilite-basalts; also in serpentine (altered peridotite) at Syracuse, N. Y.; in igneous rocks, Beaver Creek, Gunnison Co., Col.

Knopite. Near perovskite but contains cerium. In black isometric crystals. From Alnö, Sweden.

Dysanalyte. A titano-niobate of calcium and iron, like perovskite with lime replaced to some extent by iron, etc. Pseudo-isometric, probably orthorhombic. In cubic crystals. Color, iron-black. From the granular limestone of Vogtsburg, Kaiserstuhl, Baden, Germany. Has previously been called perovskite, but is in fact intermediate between the titanate, perovskite, and the niobates, pyrochlore and koppite. From Mte. Somma, Vesuvius.

A related mineral, which has also long passed as perovskite, occurs with magnetite, brookite, rutile, etc., at Magnet Cove, Ark. It is in octahedrons or cubo-octahedrons, black or brownish black in color and submetallic in luster.

See also the allied titanate, *bixbyite*, mentioned on p. 425.

Geikielite. Magnesium iron titanate, $(Mg,Fe)TiO_3$. Hexagonal, rhombohedral. Usually massive, as rolled pebbles. H. = 6. G. = 4. Color bluish or brownish black. Index, very high. From Ceylon.

Delorenzite. A titanate of iron, uranium and yttrium of uncertain composition. Orthorhombic. Prismatic habit. Color black. Resinous luster. Found in pegmatite at Graveggia, Val Vigezzo, Piedmont, Italy.

Yttrocrasite. A hydrous titanate of the yttrium earths and thorium. Orthorhombic. H. = 5·5–6. G. = 4·8. Black color with pitchy to resinous luster. Infusible. Found in Burnet Co., three miles east of Barringer Hill, Texas.

Brannerite. Essentially $(UO,TiO,UO_2)TiO_3$. Prismatic crystals or granular. Black. Streak, dark greenish brown. H. = 4·5. G. = 4·5–5·4. Found in gold placers, Stanley Basin, Idaho.

Oxygen Salts

3. NIOBATES, TANTALATES

The Niobates (Columbates) and Tantalates are chiefly salts of metaniobic and metatantalic acid, RNb_2O_6 and RTa_2O_6; also in part Pyroniobates, $R_2Nb_2O_7$, etc. Titanium is prominent in a number of the species, which are hence intermediate between the niobates and titanates. Niobium and tantalum also enter into the composition of a few rare silicates, as wöhlerite, låvenite, etc.

The following groups may be mentioned:

The isometric PYROCHLORE GROUP, including pyrochlore, microlite, etc. The tetragonal FERGUSONITE GROUP, including fergusonite and sipylite. The orthorhombic COLUMBITE GROUP, including columbite and tantalite. Also the orthorhombic SAMARSKITE GROUP, including yttrotantalite, samarskite, and ånnerodite.

The species belonging in this class are for the most part rare, and are hence but briefly described.

PYROCHLORE.

Isometric. Commonly in octanedrons; also in grains.

Cleavage: octahedral, sometimes distinct. Fracture conchoidal. Brittle. H. = 5–5·5. G. = 4·2–4·36. Luster vitreous or resinous, the latter on fracture surfaces. Color brown, dark reddish or blackish brown. Streak light brown, yellowish brown. Subtranslucent to opaque,

Comp. — Chiefly a niobate of the cerium metals, calcium and other bases, with also titanium, thorium, fluorine. Probably essentially a metaniobate with a titanate, $RNb_2O_6.R(Ti,Th)O_3$; fluorine is also present.

Obs. — Occurs in elæolite-syenite at Fredriksvärn and Laurvik, Norway; on the island Lövö, opposite Brevik, and at several points in the Langesund fiord; near Miask in the Ural Mts. Named from πῦρ, *fire*, and χλωρός, *green*, because B.B. it becomes yellowish green. A variety of pyrochlore from near Wausau, Wis., has been called *marignacite*.

Neotantalite. Composition near that of tantalite. Isometric, in octahedrons. H. = 5–6. G. = 5·2. Color clear yellow. Refractive index, 1·9. Found with kaolin at Colettes and Echassières, Dept. l'Allier, France.

Chalcolamprite. $\overset{II}{R}Nb_2O_6F_2.\overset{II}{R}SiO_3$. Isometric. In small octahedrons. H. = 5·5. G. = 3·8. Color dark gray-brown. Crystal faces show a copper-red metallic iridescence. Occurs sparingly at Narsarsuk, South Greenland. *Endeiolite* is a similar mineral from the same locality supposed to have the same composition with the substitution of the hydroxyl group for the fluorine.

Koppite. Essentially a pyroniobate of cerium, calcium, etc., near pyrochlore. In minute brown dodecahedrons. G. = 4·45–4·56. From Schelingen, Kaiserstuhl, Germany, embedded in limestone.

Hatchettolite. A tantalo-niobate of uranium, near pyrochlore. In octahedrons with *a* (100) and *m* (311). G. = 4·77–4·90. Color yellowish brown. Occurs with samarskite, at the mica mines of Mitchell Co., N. C.; from Mesa Grande, Cal.

Samirésite. A niobate of uranium, etc. Isometric. In octahedrons. G. = 5 24. Color golden-yellow. From Antsirabé, on Samiresy Hill, Madagascar.

Microlite. Essentially a calcium pyrotantalate, $Ca_2Ta_2O_7$, but containing also niobium, fluorine and a variety of bases in small amount. Isometric. Habit octahedral; crystals often very small and highly modified. H. = 5·5. G. = 5·485–5·562; 6·13 Virginia. Color pale yellow to brown, rarely hyacinth-red. $n = 1·94$. From Chesterfield, Mass., in albite; Branchville, Conn.; Rumford, Me.; Utö, Sweden; Greenland. Also in fine crystals up to 1 in. in diameter at the mica mines at Amelia Court-House, Amelia Co., Va.

Pyrrhite. Probably a niobate related to pyrochlore, and perhaps identical with microlite. Occurs in minute orange-yellow octahedrons. From Alabashka, near Mursinka in the Ural Mts.; from Mte. Somma, Vesuvius.

Risörite. A niobate of the yttrium metals. Isotropic. Color yellow-brown. H. = 5·5. G. = 4·18. In pegmatite at Risör, Norway.

FERGUSONITE. Tyrite. Bragite

Tetragonal-pyramidal. Axis $c = 1{\cdot}4643$. Crystals pyramidal or prismatic in habit.

Cleavage: *s* (111) in traces. Fracture subconchoidal. Brittle. H. = 5·5–6. G. = 5·8, diminishing to 4·3 when largely hydrated. Luster externally dull, on the fracture brilliantly vitreous and submetallic. Color brownish black; in thin scales pale liver-brown. Streak pale brown. Subtranslucent to opaque. Index, 2·19.

Comp. — Essentially a metaniobate (and tantalate) of yttrium with erbium, cerium, uranium, etc., in varying amounts; also iron, calcium, etc. General formula $\overset{\text{iii}}{\text{R}}(\text{Nb},\text{Ta})\text{O}_4$ with $\overset{\text{iii}}{\text{R}} = \text{Y},\text{Er},\text{Ce}$.

Water is usually present and sometimes in considerable amount, but probably not an original constituent; the specific gravity falls as the amount increases.

Obs. — From Cape Farewell in Greenland, in quartz; also at Ytterby and Kårarfvet, Sweden. From near Beforona, Madagascar; South Africa; Australia; Ceylon; Takayama, Mino, Japan. *Tyrite* is associated with euxenite at Hampemyr on the island of Tromö, and Helle on the mainland, Norway; *bragite* is from Helle, Narestö, etc., Norway.

Found in the United States, at Rockport, Mass., in granite; in the Brindletown gold district, Burke Co., N. C., in gold washings; with zircon in Anderson Co., S. C.; at the gadolinite locality in Llano Co., Texas, in considerable quantity.

Sipylite. A niobate of erbium chiefly, also the cerium metals, etc., near fergusonite in form. Rarely in octahedral crystals. Usually in irregular masses. G. = 4·89. Color brownish black to brownish orange. Occurs sparingly with allanite in Amherst Co., Va.

COLUMBITE-TANTALITE.

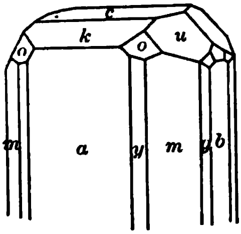
Orthorhombic. Axes $a : b : c = 0{\cdot}8285 : 1 : 0{\cdot}8898$.

yy''',	$210 \wedge 2\bar{1}0 = 45^\circ\ 0'$.	*ce*,	$001 \wedge 021 = 60^\circ\ 40'$.
mm''',	$110 \wedge 1\bar{1}0 = 79^\circ\ 17'$.	*ao*,	$100 \wedge 111 = 51^\circ\ 16'$.
gg',	$130 \wedge \bar{1}30 = 43^\circ\ 50'$.	*cu*,	$001 \wedge 133 = 43^\circ\ 48'$.
ck,	$001 \wedge 103 = 19^\circ\ 42'$.	*uu'*,	$133 \wedge \bar{1}33 = 29^\circ\ 57'$.
cq,	$001 \wedge 023 = 30^\circ\ 41'$.	*uu'''*,	$133 \wedge 1\bar{3}3 = 79^\circ\ 54'$.

Twins: tw. pl. *e* (021) common, usually contact-twins, heart-shaped (Fig. 385, p. 160), also penetration-twins; further tw. pl. *q* ($0\bar{2}3$) rare (Fig. 434, p. 169). Crystals short prismatic, often rectangular prisms with the three pinacoids prominent; also thin tabular || *a* (100); the pyramids often but slightly developed, sometimes, however, acutely terminated by *u* (133) alone. Also in large groups of parallel crystals, and massive.

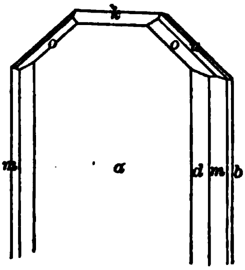
Cleavage: *a* (100) rather distinct; *b* (010) less so. Fracture subconchoidal to uneven. Brittle. H. = 6. G. = 5·3–7·3, varying with the composition (see below). Luster submetallic, often very brilliant, sub-resinous. Color iron-black, grayish and brownish black, opaque; rarely reddish brown and translucent; frequently iridescent. Streak dark red to black. Optically +. $\alpha = 2{\cdot}26$. $\beta = 2{\cdot}29$. $\gamma = 2{\cdot}34$.

967



Middletown

968



Black Hills

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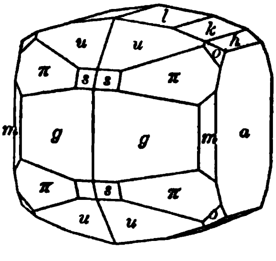


Greenland

Comp. — Niobate and tantalate of iron and manganese, $(Fe,Mn)(Nb,Ta)_2O_6$, passing by insensible gradations from normal Columbite, the nearly pure niobate, to normal Tantalite, the nearly pure tantalate. The iron and manganese also vary widely. Tin and tungsten are present in small amount. The percentage composition for $FeNb_2O_6$ = Niobium pentoxide 82·7, iron protoxide 17·3 = 100; for $FeTa_2O_6$ = Tantalum pentoxide 86·1, iron protoxide 13·9 = 100.

In some varieties, *manganocolumbite* or *manganotantalite*, the iron is largely replaced by manganese.

The connection between the specific gravity and the percentage of metallic acids is shown in the following table:

	G.	Ta_2O_5		G.	Ta_2O_5
Greenland	5·36	3·3	Bodenmais	5·92	27·1
Acworth, N. H.	5·65	15·8	Haddam	6·05	30·4
Limoges	5·70	13·8	Bodenmais	6·06	35·4
Bodenmais (*Dianite*)	5·74	13·4	Haddam	6·13	31·5
Haddam	5·85	10·0			
			Tantalite	7·03	65·6

Diff. — Distinguished (from black tourmaline, etc.) by orthorhombic crystallization, rectangular forms common; high specific gravity; submetallic luster, often with iridescent surface; cleavage much less distinct than for wolframite.

Pyr., etc. — For *tantalite*, B.B. alone unaltered. With salt of phosphorus dissolves slowly, giving an iron glass, which in R.F. is pale yellow on cooling; treated with tin on charcoal it becomes green. Decomposed on fusion with potassium bisulphate in the platinum spoon, and gives on treatment with dilute hydrochloric acid a yellow solution and a heavy white powder, which, on addition of metallic zinc, assumes a smalt-blue color; on dilution with water the blue color soon disappears. *Columbite*, when decomposed by fusion with caustic potash, and treated with hydrochloric and sulphuric acids, gives, on the addition of zinc, a blue color more lasting than with tantalite. Partially decomposed when the powdered mineral is evaporated to dryness with concentrated sulphuric acid, its color is changed to white, light gray, or yellow, and when boiled with hydrochloric acid and metallic zinc it gives a beautiful blue.

Obs. — Columbite occurs at Rabenstein and Bodenmais, Bavaria, in granite; Tammela, in Finland; Chanteloube, near Limoges, France, in pegmatite with tantalite; near Miask, in the Ilmen Mts., Russia, with samarskite; in the gold-washings of the Sanarka region in the Ural Mts.; in Greenland, in cryolite, at Ivigtut (or Evigtok), in brilliant crystals. In crystals from Ampangabé and Ambatofotsikely, Madagascar.

In the United States, in Me., at Standish, in splendent crystals in granite; also at Stoneham with cassiterite, etc., *manganotantalite* from Rumford. In N. H., at Acworth, at the mica mine. In Mass., at Chesterfield; Northfield. In Conn., at Haddam, in a granite vein; near Middletown; at Branchville, Fairfield Co., in a vein of albitic granite, in large crystals and aggregates of crystals, also in minute translucent crystals (*manganocolumbite*, upon spodumene. In N. Y., at Greenfield, with chrysoberyl. In Pa., Mineral Hill, Delaware Co. In Va., Amelia Co., in fine splendent crystals with microlite, monazite, etc. In N. C., with samarskite at the mica mines of Mitchell Co. In Col., on microcline at the Pike's Peak region; Turkey Creek, Jefferson Co. In S. D. in the Black Hills region, common in the granite veins. In Cal., King's Creek district, Fresno Co., from Rincon and *manganotantalite* from Pala.

Mangantantalite (Nordenskiöld) from Utö, Sweden, occurs with petalite, lepidolite, microlite, etc. *Manganotantalite* (Arzruni) is from gold-washings in the Sanarka region in the Ural Mts.; from Pilbarra district, West Australia.

Massive tantalite occurs in Finland, in Tammela, at Härkäsaari near Torro; in Kimito, at Skogböle; in Somero at Kaidasuo, and in Kuortane at Katiala, with lepidolite, tourmaline, and beryl; in Sweden, near Falun, at Broddbo and Finbo; in France, at Chanteloube near Limoges, in pegmatite. In the United States, in Yancey Co., N. C.; Coosa Co., Ala.; also in the Black Hills, S. D.; in large masses near Cañon City, Col.

Use. — Source of tantalum used in making filaments for incandescent electric lights.

Tapiolite. $Fe(Ta,Nb)_2O_6$. Like tantalite, but occurring in square tetragonal octahedrons. Tapiolite shows close similarities with the minerals of the Rutile Group, in which some authors place it. G. = 7·496. Color pure black. From the Kulmala farm, Tammela, Finland. In twin crystals from Topsham, Me. *Mossite*, a niobium tapiolite. Found at Berg near Moss, Norway. *Skogbölite* and *ixiolite* are twinned varieties of tapiolite.

Stibiotantalite. $(SbO)_2(Ta,Nb)_2O_6$. Orthorhombic, hemimorphic in direction of *a* axis. Polysynthetic twinning parallel to *a* (100). Cleavage *a* (perfect). H. = 5·5. G. = 6·0–7·4 (varying with composition). β. = 2·40–2·42. Fusible. Color brown, reddish yellow, yellow. Luster adamantine to resinous. Originally found in tin-bearing sands of Greenbushes, Australia. In crystals from Mesa Grande, San Diego Co., Cal.

YTTROTANTALITE.

Orthorhombic. Axes *a* : *b* : *c* = 0·5412 : 1 : 1·1330. Crystals prismatic, *mm'''* 110 ∧ 1$\bar{1}$0 = 56° 50′.

Cleavage: *b* (010) very indistinct. Fracture small conchoidal. H. = 5–5·5. G. = 5·5–5·9. Luster submetallic to vitreous and greasy. Color black, brown, brownish yellow, straw-yellow. Streak gray to colorless. Opaque to subtranslucent.

Comp. — Essentially $\overset{\text{II}}{R}\overset{\text{III}}{R}_2(Ta,Nb)_4O_{15}.4H_2O$, with $\overset{\text{II}}{R}$ = Fe, Ca, $\overset{\text{III}}{R}$ = Y, Er, Ce, etc. The water may be secondary.

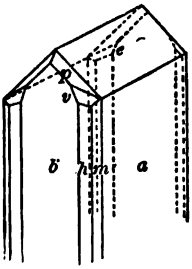
The so-called yellow yttrotantalite of Ytterby and Kårarfvet belongs to fergusonite.

Obs. — Occurs in Sweden at Ytterby, near Vaxholm, in red feldspar; at Finbo and Broddbo, near Falun, in southern Norway.

SAMARSKITE.

Orthorhombic. Axes *a* : *b* : *c* = 0·5456 : 1 : 0·5178. Crystals rectangular prisms (*a* (100), *b* (010), with *e* (101) prominent). Angles, *mm'''* 110 ∧ 1$\bar{1}$0 = 57° 14′; *ee'* 101 ∧ $\bar{1}$01 = 87°. Faces rough. Commonly massive, and in flattened embedded grains.

970



Cleavage: *b* (010) imperfect. Fracture conchoidal. Brittle. H. = 5–6. G. = 5·6–5·8. Luster vitreous to resinous, splendent. Color velvet-black. Streak dark reddish brown. Nearly opaque. Index, 2·21.

Comp. — $\overset{\text{II}}{R}_3\overset{\text{III}}{R}_2(Nb,Ta)_6O_{21}$ with $\overset{\text{II}}{R}$ = Fe, Ca, UO_2, etc.; $\overset{\text{III}}{R}$ = cerium and yttrium metals chiefly.

Pyr., etc. — In the closed tube decrepitates, glows, cracks open, and turns black. B.B. fuses on the edges to a black glass. With salt of phosphorus in both flames an emerald-green bead. With soda yields a manganese reaction. Decomposed on fusion with potassium bisulphate, yielding a yellow mass which on treatment with dilute hydrochloric acid separates white tantalic acid, and on boiling with metallic zinc gives a fine blue color. In powder sufficiently decomposed on boiling with concentrated sulphuric acid to give the blue reduction test when the acid fluid is treated with metallic zinc or tin.

Obs. — Occurs in reddish brown feldspar, with æschynite and columbite in the Ilmen mountains, near Miask, Ural Mts.; from Antanamalaza, Madagascar. In the United States rather abundant and sometimes in large masses up to 20 lbs. at the mica mines in Mitchell Co., N. C., intimately associated with columbite; sparingly elsewhere.

Ampangabéite. A niobate of uranium, etc. In rectangular prisms, probably orthorhombic. Color brownish red. Luster greasy. H. = 4. G. = 3·97–4·29. Fuses to a black slag. Easily soluble in hydrochloric acid. Radioactive. Found in parallel growth with columbite at Ampangabé and Ambatofotsikely, Madagascar.

Ånnerödite. Essentially a pyro-niobate of uranium and yttrium. In prismatic crystals, often resembling columbite. H. = 6. G. = 5·7. Color black. From the pegmatite vein at Ånneröd, near Moss, Norway.

Hielmite. A stanno-tantalate (and niobate) of yttrium, iron, manganese, calcium. Crystals (orthorhombic) usually rough; massive. G. = 5·82. Color pure black. From the Kårarfvet mine, Falun, Sweden.

Æschynite. A niobate and titanate (thorate) of the cerium metals chiefly, also in small amount iron, calcium, etc. Crystals prismatic, orthorhombic. Fracture small conchoidal. Brittle. H. = 5–6. G. = 4·93 Hitterö; 5·168 Miask. Luster submetallic to resinous, nearly dull. Color nearly black, inclining to brownish yellow when translucent.

From Miask in the Ilmen Mts., Russia, in feldspar with mica and zircon; also with euclase in the gold sands of the Orenburg District, Southern Ural Mts. From Hitterö, Norway. Named from αἰσχύνη, *shame*, by Berzelius, in allusion to the inability of chemical science, at the time of its discovery, to separate some of its constituents.

Polymignite. A niobate and titanate (zirconate) of the cerium metals, iron, calcium. Crystals slender prisms, vertically striated. G. = 4·77–4·85. Color black. Occurs at Frederiksvärn, Norway.

Euxenite. A niobate and titanate of yttrium, erbium, cerium and uranium. Crystals rare; commonly massive. H. = 6·5. G. = 4·7–5·0. Color brownish black.

Occurs in Norway, at Jölster near Tvedestrand; at Alve, etc., near Arendal; from Greenland; from various localities in Madagascar.

Loranskite and **Wiikite** are euxenite-like minerals from Impilaks, Finland. Usually in irregular masses but orthorhombic crystals are noted. H. = 6. G. = 3·8–4·8. Color black to brown and yellow.

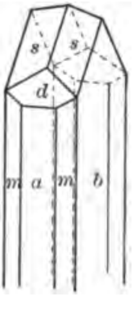
Polycrase. A niobate and titanate of yttrium, erbium, cerium, uranium, like euxenite. Crystals thin prismatic, orthorhombic. Fracture conchoidal. H. = 5–6. G. = 4·97–5·04. Luster vitreous to resinous. Color black, brownish in splinters.

From Hitterö, Norway, in granite with gadolinite; at Slättåkra, Småland, Sweden. In the United States, in N. C., in the gold-washings on Davis land, Henderson Co., with zircon, monazite, xenotime, magnetite; also in S. C., four miles from Marietta in Greenville Co. Named from πολύς, *many*, and κρᾶσις, *mixture*.

Blomstrandine-Priorite. Niobates and titanates of yttrium, erbium, cerium and uranium, similar to the *euxenite-polycrase* series. The two series may be dimorphous. The ratio of $Nb_2O_5 : TiO_2$ ranges from 1 : 2 in priorite to 1 : 6 in blomstrandine. Orthohombic. Crystals tabular parallel to *b* (010). Most prominent forms are *b* (010), *c* (001) and *n* (130). G. = 4·8–4·9. Color brownish black. Originally found in a pegmatite vein at Urstad, Island of Hitterö, Norway. Also noted from Arendal and elsewhere in southern Norway and from Miask, Ilmen Mts., Russia.

Betafite. A niobate and titanate of uranium, etc. Isometric with octahedron and dodecahedron. G. = 3·75–4·17. Color, a greenish black. Opaque. Greasy luster. Found in pegmatites from various localities in Madagascar, including Ambolotara, near Betafo.

971



Epistolite. A niobate of uncertain composition. Analysis shows chiefly SiO_2, TiO_2, Na_2O, H_2O. Monoclinic. In rectangular plates, also in aggregates of curved folia. Basal cleavage perfect. H. = 1–1·5. G. = 2·9. Color white, grayish, brownish. Refractive index 1·67. Found in pegmatite veins or in massive albite from Julianehaab, Greenland.

Plumboniobite. A niobate of yttrium, uranium, lead, iron, etc. Amorphous. H. = 5–5·5. G. = 4·81. Color dark brown to black. Found in mica mines at Morogoro, German East Africa.

Oxygen Salts

4. PHOSPHATES, ARSENATES, VANADATES, ANTIMONATES

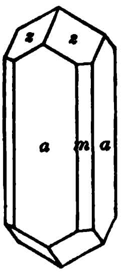
A. Anhydrous Phosphates, Arsenates, Vanadates, Antimonates

Normal phosphoric acid is H_3PO_4, and consequently normal phosphates have the formulas $\overset{I}{R}_3PO_4$, $\overset{II}{R}_3(PO_4)_2$ and $\overset{III}{R}PO_4$, and similarly for the arsenates, etc. Only a comparatively small number of species conform to this simple formula. Most species contain more than one metallic element, and in the prominent Apatite Group the radical (CaF), (CaCl) or (PbCl) enters; in the Wagnerite Group we have similarly $(\overset{II}{R}F)$ or (ROH).

XENOTIME.

Tetragonal. Axis $c = 0·6187$, zz' $(111 \wedge \bar{1}11) = 55° 30'$, zz'' $(111 \wedge \bar{1}\bar{1}1) = 82° 22'$. In crystals resembling zircon in habit; sometimes compounded with zircon in parallel position (Fig. 462, p. 173). In rolled grains.

972



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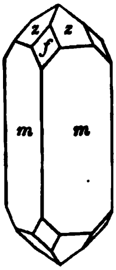


Cleavage: *m* (110) perfect. Fracture uneven and splintery. Brittle. H. = 4–5. G. = 4·45–4·56. Luster resinous to vitreous. Color yellowish brown, reddish brown, hair-brown, flesh-red, grayish white, wine-yellow, pale yellow; streak pale brown, yellowish or reddish. Opaque. Optically +. $\omega = 1·72$. $\epsilon = 1·81$.

Comp. — Essentially yttrium phosphate, YPO_4 or $Y_2O_3.P_2O_5$ = Phosphorus pentoxide 38·6, yttria 61·4 = 100. The yttrium metals may include erbium in large amount; cerium is sometimes present; also silicon and thorium as in monazite.

Pyr., etc. — B.B. infusible. When moistened with sulphuric acid colors the flame bluish green. Difficultly soluble in salt of phosphorus. Insoluble in acids.

Diff. — Resembles zircon in its tetragonal form, but distinguished by inferior hardness and perfect prismatic cleavage.

Obs. — Occurs as an accessory mineral in granite veins; sometimes in minute embedded crystals generally distributed in granitic and gneissoid rocks. Found at Hitterö; at Moss, Kragerö, and from pegmatite veins at other points in Norway; at Ytterby, Sweden; the Fibia Berg, S.W. from St. Gothard and the Binnental, Switzerland. An accessory constituent in the muscovite-granites of Brazil. *Hussakite* was a xenotime from Brazil erroneously thought to contain large amounts of SO_3.

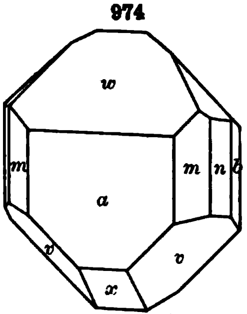
In the United States, in the gold washings of Clarksville, Ga.; in N. C., Burke Co., Henderson Co., Mitchell Co.; in brilliant crystals in Alexander Co. with rutile, etc.; with tysonite near Pike's Peak, Col.; rare on New York Island.

MONAZITE

Monoclinic. Axes $a : b : c = 0{\cdot}9693 : 1 : 0{\cdot}9256$; $\beta = 76° 20'$.

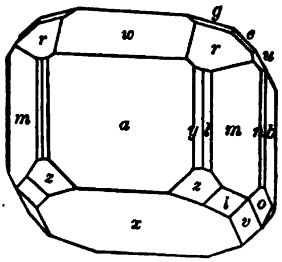
mm''', $110 \wedge 1\bar{1}0 = 86° 34'$.
aw, $100 \wedge 101 = 39° 12\tfrac{1}{2}'$.
$a'x$, $\bar{1}00 \wedge \bar{1}01 = 53° 31'$.
ee', $011 \wedge 0\bar{1}1 = 83° 56'$.
rr', $111 \wedge 1\bar{1}1 = 60° 40'$.
vv', $\bar{1}11 \wedge \bar{1}\bar{1}1 = 73° 19'$.

974



Norwich, Ct.

975



Switzerland

Crystals commonly small, often flattened || *a* (100) or elongated || axis *b*; sometimes prismatic by extension of *v* (111); also large and coarse. In masses yielding angular fragments; in rolled grains.

Cleavage: *c* (001) sometimes perfect (parting?); also, *a* (100) distinct; *b* (010) difficult; sometimes showing parting || *c* (001), *m* (110). Fracture conchoidal to uneven. Brittle. H. = 5–5·5. G. = 4·9–5·3; mostly 5·0 to 5·2. Luster inclining to resinous. Color hyacinth-red, clove-brown, reddish or yellowish brown. Subtransparent to subtranslucent. Optically +. Ax. pl. ⊥ *b* (010) and nearly || *a* (100). $Bx_a \wedge c$ axis = + 1° to 4°. Dispersion $\rho < v$ weak; horizontal weak. 2V = 14°. $\alpha = 1{\cdot}786$. $\beta = 1{\cdot}788$. $\gamma = 1{\cdot}837$.

Comp. — Phosphate of the cerium metals, essentially $(Ce,La,Di)PO_4$.

Most analyses show the presence of ThO_2 and SiO_2, usually, but not always, in the proper amount to form thorium silicate; that this is mechanically present is not certain but possible.

Pyr., etc. — B.B. infusible, turns gray, and when moistened with sulphuric acid colors the flame bluish green. With borax gives a bead yellow while hot and colorless on cooling; a saturated bead becomes enamel-white on flaming. Difficultly soluble in hydrochloric acid.

Obs. — Rather abundantly distributed as an accessory constituent of gneissoid rocks in certain regions, thus in North Carolina and Brazil. Occurs near Zlatoust in the Ilmen Mts., Russia, in granite. In Norway, near Arendal, and at Anneröd. In small yellow or brown crystals (*turnerite*) in Dauphiné, France, and Switzerland. Found also in the gold washings of Antioquia, Colombia; in the diamond gravels of Brazil. In crystals from Trundle near Condobolin and Emmaville, New South Wales; California Creek, Queensland; Olary, South Australia. In Madagascar at various localities.

In the United States, formerly found with the sillimanite of Norwich, and at Portland, Conn.; also at Yorktown, N. Y. In large coarse crystals and masses in albitic granite with microlite, etc., at Amelia Court-House, Va. In Alexander Co., N. C., in splendent crystals; in Mitchell, Madison, Burke, and McDowell counties, obtained in large quantities in rolled grains by washing the gravels. In the gold sands of southern Idaho.

Monazite is named from *μονάζειν, to be solitary*, in allusion to its rare occurrence.

Cryptolite occurs in wine-yellow prisms and grains in the green and red apatite of Arendal, Norway, and is discovered on putting the apatite in dilute nitric acid. It is probably monazite.

Use. — Monazite is the chief source of thorium oxide which is used in the manufacture of incandescent gaslight mantles.

Berzeliite. $R_3As_2O_8(R = Ca,Mg,Mn,Na_2)$. Isometric, usually massive. G. = 4·03. Color bright yellow. From Långban, Sweden. *Pyrrharsenite* from the Sjö mines, Sweden, contains also antimony; color yellowish red. *Caryinite*, associated with berzeliite, is related, but contains lead; massive (monoclinic).

Monimolite. An antimonate of lead, iron, and sometimes calcium; in part, $R_3Sb_2O_8$. Usually in octahedrons; massive, incrusting. G. = 6·58. Color yellowish or brownish green. From the Harstig mine, Pajsberg, Sweden.

Carminite. Perhaps $Pb_3As_2O_8.10FeAsO_4$. In clusters of fine needles; also in spheroidal forms. G. = 4·105. Color carmine to tile-red. From the Luise mine at Horhausen, Nassau, Germany.

Georgiadésite. $Pb_3(AsO_4)_2.3PbCl_2$. Orthorhombic. In small crystals with hexagonal outline. H. = 3·5. G. = 7·1. Resinous luster. Color white, brownish yellow. Found on lead slags at Laurium, Greece.

Pucherite. Bismuth vanadate, $BiVO_4$. In small orthorhombic crystals. H. = 4. G. = 6·249. Color reddish brown. Optically −. β = 2·50. From the Pucher Mine, Schneeberg, Saxony; San Diego Co., Cal.

Armangite. $Mn_3(AsO_3)_2$. Hexagonal-rhombohedral. Prismatic habit. H. = 4. G. = 4·23. Poor basal cleavage. Color black, streak brown. Optically −. High refractive index. From Långban, Sweden.

Triphylite Group. Orthorhombic

		$a : b : c$
Triphylite	$Li(Fe,Mn)PO_4$	0·4348 : 1 : 0·5265
Lithiophilite	$Li(Mn,Fe)PO_4$	
Natrophilite	$NaMnPO_4$	

Orthophosphates of an alkali metal, lithium or sodium, with iron and manganese.

TRIPHYLITE-LITHIOPHILITE.

Orthorhombic. Axes $a : b : c$ = 0·4348 : 1 : 0·5265. Crystals rare, usually coarse and faces uneven. Commonly massive, cleavable to compact.

Cleavage: c (001) perfect; b (010) nearly perfect; m (110) interrupted. Fracture uneven to subconchoidal. H. = 4·5–5. G = 3·42–3·56. Luster vitreous to resinous. Color greenish gray to bluish in triphylite; also pale pink to yellow and clove-brown in lithiophilite. Streak uncolored to grayish white. Transparent to translucent. Axial angle variable, 0°–90°. Mean index, 1·68.

Comp. — A phosphate of iron, manganese and lithium, $Li(Fe,Mn)PO_4$, varying from the bluish gray TRIPHYLITE with little manganese to the salmon-pink or clove-brown LITHIOPHILITE with but little iron.

Typical *Triphylite* is $LiFePO_4$ = Phosphorus pentoxide 45·0, iron protoxide 45·5, lithia 9·5 = 100. Typical *Lithiophilite* is $LiMnPO_4$ = Phosphorus pentoxide 45·3, manganese protoxide 45·1, lithia 9·6 = 100. Both Fe and Mn are always present.

Pyr., etc. — In the closed tube sometimes decrepitates, turns to a dark color, and gives off traces of water. B.B. fuses at 1·5, coloring the flame beautiful lithia-red in streaks, with a pale bluish green on the exterior of the cone of flame. With the fluxes reacts for iron and manganese; the iron reaction is feeble in pure lithiophilite. Soluble in hydrochloric acid.

Obs. — *Triphylite* is often associated with spodumene; occurs at Rabenstein, near Zwiesel, in Bavaria; Keityö, Finland; Norwich, Mass.; Peru, Me.; Grafton, N. H. Named from τρίς, *threefold*, and φυλή, *family*, in allusion to its containing three phosphates.

Lithiophilite occurs at Branchville, Fairfield Co., Conn., in a vein of albitic granite, with spodumene, manganese phosphates, etc.; also at Norway, Me., in crystals from Pala, Cal. Named from *lithium* and φιλός, *friend*.

Natrophilite. $NaMnPO_4$. Near triphylite in form. Chiefly massive, cleavable. H. = 4·5–5. G. = 3·41. Color deep wine-yellow. Occurs sparingly at Branchville, Conn.

Graftonite. $(Fe,Mn,Ca)_3P_2O_8$. Monoclinic. H. = 5. G. = 3·7. Color when fresh salmon-pink, usually dark from alteration. Fusible. Occurs in laminated intergrowths with triphylite in a pegmatite from Grafton, N. H.

Beryllonite. A phosphate of sodium and beryllium, $NaBePO_4$. Crystals short prismatic to tabular, orthorhombic. H. = 5·5–6. G. = 2·845. Luster vitreous; on *c* (001) pearly. Colorless to white or pale yellowish. Optically −. $\beta = 1·558$. From Stoneham, Me.

Apatite Group

General formula	$R_5(F,Cl)[(P,As,V)O_4]_3 = (R(F,Cl))R_4[(P,As,V)O_4]_3$;		
Apatite	$(CaF)Ca_4(PO_4)_3$	Fluor-apatite	$c = 0·7346$
	or $(CaCl)Ca_4(PO_4)_3$	Chlor-apatite	
Pyromorphite	$(PbCl)Pb_4(PO_4)_3$		0·7362
Mimetite	$(PbCl)Pb_4(AsO_4)_3$		0·7224
Vanadinite	$(PbCl)Pb_4(VO_4)_3$		0·7122

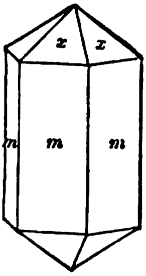
In addition to the above species, there are also certain intermediate compounds containing lead and calcium; others with phosphorus and arsenic, or arsenic and vanadium, as noted beyond. Further the rare calcium arsenate, Svabite, also seems to belong in this group. The radicals CaO, Ca.OH, may possibly replace the CaF radical in apatite. A probable member of the group, *wilkeite*, contains CO_3, SiO_2 and SO_4 in addition to usual radicals. *Fermorite* contains strontium.

The species of the APATITE GROUP crystallize in the hexagonal system, but all show, either by the subordinate faces, or in etching-figures, that they belong to the pyramidal class (p. 100). They are chemically phosphates, arsenates, vanadates of calcium or lead (also manganese), with chlorine or fluorine. The latter element is probably present as a univalent radical CaF (or CaCl), etc., in general RF (or RCl), replacing one hydrogen atom in the acid $\overset{I}{R}_9(PO_4)_3$, so that the general formula is $(\overset{II}{R}F)\overset{II}{R}_4(PO_4)_3$, and similarly for the arsenates. This is a more correct way of viewing the composition than the other method sometimes adopted, viz., $3R_3(PO_4)_2.RF_2$, etc.

APATITE.

Hexagonal-pyramidal. Axis $c = 0·7346$.

976



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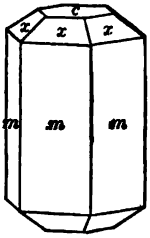

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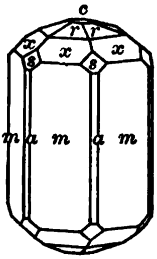

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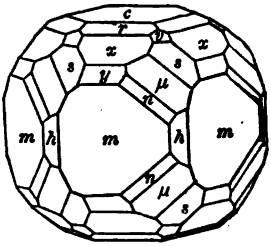
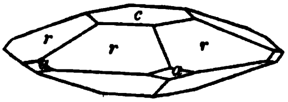


cr, $0001 \wedge 10\bar{1}2 = 22° 59'$.
cx, $0001 \wedge 10\bar{1}1 = 40° 18'$.
cy, $0001 \wedge 20\bar{2}1 = 59° 29'$.
rr', $10\bar{1}2 \wedge 01\bar{1}2 = 22° 31'$.
xx', $10\bar{1}1 \wedge \bar{1}011 = 37° 44\frac{1}{2}'$.
ss', $11\bar{2}1 \wedge \bar{1}2\bar{1}1 = 48° 50'$.
$m\mu$, $10\bar{1}0 \wedge 21\bar{3}1 = 30° 20'$.
ms, $10\bar{1}0 \wedge 11\bar{2}1 = 44° 17'$.

980



Crystals varying from long prismatic to short prismatic and tabular. Also globular and reniform, with a fibrous or imperfectly columnar structure; massive, structure granular to compact.

Cleavage: *c* (0001) imperfect; *m* ($10\bar{1}0$) more so. Fracture conchoidal and uneven. Brittle. H. = 5, sometimes 4·5 when massive. G. = 3·17–3·23 crystals. Luster vitreous, inclining to subresinous. Streak white. Color usually sea-green, bluish green; often violet-blue; sometimes white; occasionally yellow, gray, red, flesh-red and brown. Transparent to opaque. Optically −. Birefringence low. $\omega = 1·6461$, $\epsilon = 1·6417$.

Var. — 1. *Ordinary.* Crystallized, or cleavable and granular massive. Colorless to green, blue, yellow, flesh-red. (*a*) The *asparagus-stone,* originally from Murcia, Spain, is yellowish green. *Moroxite,* from Arendal, Norway, is in greenish blue and bluish crystals. (*b*) *Lasurapatite* is a sky-blue variety with lapis-lazuli in Siberia. (*c*) *Francolite,* from Wheal Franco, near Tavistock, Devonshire, England, occurs in small crystalline stalactitic masses and in minute curving crystals.

Ordinary apatite is *fluor-apatite,* containing fluorine often with only a trace of chlorine, up to 0·5 p. c.; rarely chlorine preponderates, and sometimes fluorine is entirely absent.

2. *Manganapatite* contains manganese replacing calcium to 10·5 p. c. MnO; color dark bluish green.

3. *Vœlckerite* is name given to the possible isomorphous molecule, $Ca_4(CaO)(PO_4)_3$ and *hydroxyapatite* to $Ca_4(Ca.OH)(PO_4)_3$.

4. *Fibrous, concretionary, stalactitic. Phosphorite* includes the fibrous concretionary and partly scaly mineral from Estremadura, Spain, and elsewhere. *Eupyrchroite,* from Crown Point, N. Y., belongs here; it is concentric in structure. *Staffelite* occurs incrusting the phosphorite of Staffel, Germany, in botryoidal, reniform, or stalactitic masses, fibrous and radiating. See p. 597.

5. *Earthy apatite; Osteolite.* Mostly altered apatite; *coprolites* are impure calcium phosphate.

Comp. — For *Fluor-apatite* $(CaF)Ca_4(PO_4)_3$; and for *Chlor-apatite* $(CaCl)Ca_4(PO_4)_3$; also written $3Ca_3P_2O_8.CaF_2$ and $3Ca_3P_2O_8.CaCl_2$. There are also intermediate compounds containing both fluorine and chlorine. The percentage composition for these normal varieties is as follows:

Fluor-apatite	P_2O_5 42·3	CaO 55·5	F 3·8 = 101·6	or $Ca_3P_2O_8$ 92·25	CaF_2	7·75 = 100
Chlor-apatite	P_2O_5 41·0	CaO 53·8	Cl 6·8 = 101·6	or $Ca_3P_2O_8$ 89·4	$CaCl_2$	10·6 = 100

Fluor-apatite is much more common than the other variety; here belongs the apatite of the Alps, Spain, St. Lawrence Co., N. Y., Canada. Apatites in which chlorine is prominent are rare; this is true of some Norwegian kinds.

Pyr., etc. — B.B. in the forceps fuses with difficulty on the edges (F. = 4·5–5), coloring the flame reddish yellow; moistened with sulphuric acid and heated colors the flame pale bluish green (phosphoric acid). Dissolves in hydrochloric and nitric acids, yielding with sulphuric acid a copious precipitate of calcium sulphate; the dilute nitric acid solution gives sometimes a precipitate of silver chloride on addition of silver nitrate. Most varieties will give a slight test for fluorine, when heated with potassium bisulphate in a closed tube.

Diff. — Characterized by the common hexagonal form, but softer than beryl, being scratched by a knife; does not effervesce in acid (like calcite); difficultly fusible; yields a green flame B.B. after being moistened with sulphuric acid.

Micro. — Recognized in thin sections by its moderately high relief; extremely low birefringence (hence not often showing a distinct axial figure in basal sections), the interference colors in ordinary sections scarcely rising above gray of the first order; parallel extinction and negative extension; columnar form; lack of color and cleavage; and by the rude cross parting seen as occasional cracks crossing the prism.

Artif. — Apatite may be prepared artificially by fusing sodium phosphate with calcium fluoride or calcium chloride.

Obs. — Apatite occurs in rocks of various kinds and ages, but is most common in metamorphic crystalline rocks, especially in granular limestone and in many metalliferous veins, particularly those of tin, in gneiss, syenite, hornblendic gneiss, mica schist, beds of iron ore; occasionally in serpentine. In the form of minute microscopic crystals it has an almost universal distribution as an accessory rock-forming mineral. It is found in all kinds of igneous rocks and is one of the earliest products of crystallization. In larger crystals it is especially characteristic of the pegmatite facies of igneous rocks, particularly the granites, and occurs there associated with quartz, feldspar, tourmaline, muscovite, beryl, etc. It is sometimes present in ordinary stratified limestone, beds of sandstone or shale of the Silurian, Carboniferous, Jurassic, Cretaceous, or Tertiary. It has been observed as the petrifying material of wood.

Among its localities are Ehrenfriedersdorf in Saxony; Schwarzenstein, the Knappenwand in Untersulzbachtal and Zillertal in the Tyrol, Austria; St. Gothard, Tavetsch, etc., in Switzerland; Mussa-Alp in Piedmont, Italy, white or colorless; Zinnwald and Schlackenwald in Bohemia; at Gellivare, Sweden; in England, in Cornwall, with tin ores; in Cumberland, at Carrock Fells; in Devonshire, cream-colored at Bovey Tracey, and at Wheal Franco (*francolite*). The *asparagus-stone* or *spargelstein* of Jumilla, in Murcia, Spain, is pale yellowish green in color. Large quantities of apatite are mined in Norway at Kragerö; also at Ödegaard, near Bamle, and elsewhere.

In Me., on Long Island, Blue-hill Bay; in fine purple crystals of gem-quality from Auburn. In N. H., Westmoreland. In Mass., at Norwich; at Bolton abundant. In Conn., at Branchville (*manganapatite*), also greenish white and colorless; at Haddam Neck. In N. Y., common in St. Lawrence Co., in granular limestone, also Jefferson Co.; Sandford mine, East Moriah, Essex Co., in magnetite; near Edenville, Orange Co.; at Tilly Foster iron mine. In Pa., at Leiperville, Delaware Co.; in Chester Co. In N. C., at Stony Point, Alexander Co., etc. In lavender-colored crystals from Mesa Grande, Cal.

In extensive beds in the Laurentian gneiss of Canada, usually associated with limestone, and accompanied by pyroxene, amphibole, titanite, zircon, garnet, vesuvianite and many other species. Prominent mines are in Ottawa County, Quebec, in the townships of Buckingham, Templeton, Portland, Hull, and Wakefield. Also in Renfrew county, Ontario, and in Lanark, Leeds, and Frontenac counties.

Apatite was named by Werner from *ἀπατάειν, to deceive*, older mineralogists having referred it to aquamarine, chrysolite, amethyst, fluorite, tourmaline, etc.

Besides the definite *mineral phosphates*, including normal apatite, phosphorite, etc., there are also extensive deposits of amorphous phosphates, consisting largely of "bone phosphate" ($Ca_3P_2O_8$), of great economic importance, though not having a definite chemical composition and hence not strictly belonging to pure mineralogy. Here belong the phosphatic nodules, coprolites, bone beds, guano, etc. Extensive phosphatic deposits also occur in North Carolina, Alabama, Florida, Tennessee, and in the western states, Idaho, Utah, and Wyoming. Guano is bone phosphate of lime, mixed with the hydrous phosphates, and generally with some calcium carbonate, and often a little magnesia, alumina, iron, silica, gypsum, and other impurities.

Use. — Apatite and phosphate rock are used chiefly as sources of mineral fertilizers. Some clear finely colored varieties of apatite may be used as gem stones. The mineral is too soft, however, to permit of extensive use for this purpose.

STAFFELITE. A carbonated calcium phosphate. Occurs incrusting the phosphorite of Staffel, Germany, in botryoidal or stalactitic masses, fibrous and radiating; it is the result of the action of carbonated waters. H. = 4. G. = 3·128. Color leek- to dark green, greenish yellow. *Dahllite*, from Bamle, Norway, is similar.

Fermorite. A member of the Apatite Group. $(Ca,Sr)_4[Ca(OH,F)][(P,As)O_4]_3$. H. = 5. G. = 3·52. Color pale pinkish white to white. Uniaxial, − . Index = 1·66. Found with manganese ores at Sitapar, Chhindwara District, Central provinces, India.

Wilkeite. $3Ca_3(PO_4)_2.CaCO_3.3Ca_3[(SiO_4)(SO_4)].CaO$. Probably a member of *Apatite Group*. Hexagonal. H. = 5. G. = 3·23. Color pale rose-red, yellow. Optically −. Index, 1·64. Fusible at 5·5. Dissolves in acids with separation of silica. In crystalline limestone at Crestmore, Riverside Co., Cal.

PYROMORPHITE. Green Lead Ore.

Hexagonal-pyramidal. Axis $c = 0·7362$.

Crystals prismatic, often in rounded barrel-shaped forms; also in branching groups of prismatic crystals in nearly parallel position, tapering down to a slender point. Often globular, reniform, and botryoidal or in wart-like shapes, with usually a subcolumnar structure; also fibrous, and granular.

Cleavage: *m* (10$\bar{1}$0), *x* (10$\bar{1}$1) in traces. Fracture subconchoidal, uneven. Brittle. H. = 3·5–4. G. = 6·5–7·1 mostly, when pure; 5·9–6·5, when containing lime. Luster resinous. Color green, yellow, and brown, of different shades; sometimes wax-yellow and fine orange-yellow; also grayish white to milk-white. Streak white, sometimes yellowish. Subtransparent to subtranslucent. Optically −. $\omega = 2·050$. $\epsilon = 2·042$.

981

Var. — 1. *Ordinary.* (*a*) *In crystals* as described; sometimes yellow and in rounded forms resembling campylite (*pseudo-campylite*). (*b*) In *acicular* and *moss-like* aggregations. (*c*) *Concretionary* groups or masses of crystals, having the surface angular. (*d*) *Fibrou* (*e*) *Granular massive.* (*f*) *Earthy;* incrusting.

2. *Polyspharite.* Containing lime; color brown of different shades, yellowish gray, pale yellow to nearly white; streak white; G. = 5·89–6·44. Rarely in separate crystals; usually in groups, globular, mammillary. *Miesite,* from Mies in Bohemia, is a brown variety. *Nussierite* is similar and impure, from Nussière, near Beaujeu, France; color yellow, greenish or grayish; G. = 5·042. 3. *Chromiferous;* color brilliant red and orange. 4. *Arseniferous;* color green to white; G. = 5·5–6·6. 5. *Pseudomorphous;* (*a*) after galena; (*b*) cerussite.

Comp. — $(PbCl)Pb_4(PO_4)_3$ or also written $3Pb_3P_2O_8.PbCl_2$ = Phosphorus pentoxide 15·7, lead protoxide 82·2, chlorine 2·6 = 100·5, or Lead phosphate 89·7, lead chloride 10·3 = 100.

The phosphorus is often replaced by arsenic, and as the amount increases the species passes into mimetite. Calcium also replaces the lead to a considerable extent.

Pyr., etc. — In the closed tube gives a white sublimate of lead chloride. B.B. in the forceps fuses easily (F. = 1·5), coloring the flame bluish green; on charcoal fuses without reduction to a globule, which on cooling assumes a crystalline polyhedral form, while the coal is coated white from lead chloride and, nearer the assay, yellow from lead oxide. With soda on charcoal yields metallic lead; some varieties contain arsenic, and give the odor of garlic in R.F. on charcoal. Soluble in nitric acid.

Diff. — Distinguished by its hexagonal form; high specific gravity; resinous luster; blowpipe characters.

Obs. — Pyromorphite occurs principally in veins, and accompanies other ores of lead. At Poullaouen and Huelgoet in Brittany, France; at Zschopau and other places in Saxony, Germany; at Přibram, Bleistadt, in Bohemia; in fine crystals at Ems, Braubach, in Nassau, Germany; also at Dernbach in Nassau; in Siberia at Beresov and in the Nerchinsk mining district; in England, in Cornwall, green and brown; Devon, gray; Derbyshire, green and yellow; Cumberland, golden yellow; in Scotland, Leadhill, red and orange. From Broken Hill and elsewhere, New South Wales.

In the United States, has been found very fine at Phenixville, Pa.; also in Me., at Lubec and Lenox; in N. Y., a mile south of Sing Sing; in Davidson Co., N. C., also in Cabarrus and Caldwell Cos.; from Mullan, Burke, Wardner and Mace, Idaho.

Named from πῦρ, *fire,* μορφή, *form,* alluding to the crystalline form the globule assumes on cooling. This species passes into mimetite.

Use. — A minor ore of lead.

MIMETITE.

Hexagonal-pyramidal. Axis $c = 0·7224$.

Habit of crystals like pyromorphite; sometimes rounded to globular forms. Also in mammillary crusts.

Cleavage: x $(10\bar{1}1)$ imperfect. Fracture uneven. Brittle. H. = 3·5. G. = 7·0–7·25. Luster resinous. Color pale yellow, passing into brown; orange-yellow; white or colorless. Streak white or nearly so. Subtransparent to translucent. Optically −. $\omega = 2·135$. $\epsilon = 2·118$.

Var. — 1. *Ordinary.* (*a*) *In crystals,* usually in rounded aggregates. (*b*) *Capillary* or filamentous, especially marked in a variety from St. Prix-sous-Beuvray, France; somewhat like asbestus, and straw-yellow in color. (*c*) *Concretionary.*

Campylite, from Drygill in Cumberland, England, has G. = 7·218, and is in barrel-shaped crystals (whence the name, from καμπύλος, *curved*), yellowish to brown and brownish red; contains 3 p. c. P_2O_5.

Comp. — $(PbCl)Pb_4(AsO_4)_3$; also written $3Pb_3As_2O_8.PbCl_2$ = Arsenic pentoxide 23·2, lead protoxide 74·9, chlorine 2·4 = 100·5, or Lead arsenate 90·7, lead chloride 9·3 = 100.

Phosphorus replaces the arsenic in part, and calcium the lead. *Endlichite* (p. 599) is intermediate between mimetite and vanadinite.

Pyr., etc. — In the closed tube like pyromorphite. B.B. fuses at 1, and on charcoal gives in R.F. an arsenical odor, and is easily reduced to metallic lead, coating the coal at first with lead chloride, and later with arsenic trioxide and lead oxide. Soluble in nitric acid.

Obs. — Occurs in England near Redruth and elsewhere in Cornwall; Beer Alston, Devonshire; in Cumberland; in France near Pontgibaud, Puy-de-Dôme; in Germany at Johanngeorgenstadt, in fine yellow crystals, at Zinnwald; at Nerchinsk, Siberia; Långban, Sweden; from Santa Eulalia, Chihuahua, Mexico; at the Brookdale mine, Phenixville, Pa.; Eureka, Utah.

Named from *μιμητής, imitator*, it closely resembling pyromorphite.

Use. — A minor ore of lead.

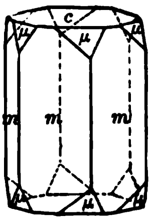
VANADINITE.

Hexagonal-pyramidal. Axis $c = 0{\cdot}7122$.

Crystals prismatic, with smooth faces and sharp edges; sometimes cavernous, the crystals hollow prisms; also in rounded forms and in parallel groupings like pyromorphite. In implanted globules or incrustations.

Fracture uneven, or flat conchoidal. Brittle. H. = 2·75–3. G. = 6·66–7·10. Luster of surface of fracture resinous. Color deep ruby-red, light brownish yellow, straw-yellow, reddish brown. Streak white or yellowish. Subtranslucent to opaque. Optically −. $\omega = 2{\cdot}354$. $\epsilon = 2{\cdot}299$.

982



983

Comp. — $(PbCl)Pb_4(VO_4)_3$, also written $3Pb_3V_2O_8.PbCl_2$ = Vanadium pentoxide 19·4, lead protoxide 78·7, chlorine 2·5 = 100·6, or Lead vanadate 90·2, lead chloride 9·8 = 100.

Phosphorus is sparingly present, also sometimes arsenic, both replacing vanadium. In *endlichite* the ratio of V : As = 1 : 1 nearly.

Pyr., etc. — In the closed tube decrepitates and yields a faint white sublimate. B.B. fuses easily, and on charcoal to a black lustrous mass, which in R.F. yields metallic lead and a coating of lead chloride; after completely oxidizing the lead in O.F. the black residue gives with salt of phosphorus an emerald-green bead in R.F., which becomes light yellow in O.F. Decomposed by hydrochloric acid.

Obs. — First discovered at Zimapan in Mexico. Later obtained at Wanlockhead in Dumfriesshire, Scotland; also at Berezov in the Ural Mts., with pyromorphite; and near Kappel in Carinthia, in crystals; at Undenäs, Bölet, Sweden. In the Sierra de Córdoba, Argentine Republic.

In the United States, sparingly near Sing Sing, N. Y. Abundant in the mining regions of Arizona and New Mexico, often associated with wulfenite and descloizite; in Ariz., at the mines in Yuma Co., in brilliant deep red crystals; Vulture, Phœnix, etc., in Maricopa Co.; the Mammoth gold mine, near Oracle, Pinal Co.; from Yavapai Co. In N. M. at Lake Valley, Sierra Co. (*endlichite*); and the Mimbres mines near Georgetown; Hillsboro; Magdalena.

Use. — A source of vanadium and a minor ore of lead.

Hedyphane. From Långban, Sweden; has ordinarily been included as a calcium variety of mimetite. Massive, cleavable. Color yellowish white. From Harstig mine, Pajsberg, Sweden.

Svabite. A calcium arsenate, related to the species of the Apatite Group. Crystals hexagonal prisms; colorless; $c = 0{\cdot}7143$. H. = 5. G. = 3·52. From the Harstig mine, Pajsberg, and near Nordmark, Sweden.

Wagnerite Group. Monoclinic

		$a : b : c$	β
Wagnerite	$(MgF)MgPO_4$	1·9145 : 1 : 1·5059;	71° 53′
Triplite	$(RF)RPO_4$, R = Fe : Mn = 2 : 1, 1 : 1, etc.		
Triploidite	$(ROH)RPO_4$, R = Mn : Fe = 3 : 1	1·8572 : 1 : 1·4925;	71° 46′
Adelite	$(MgOH)CaAsO_4$	2·1978 : 1 : 1·5642;	73° 15′
Tilasite	$(MgF)CaAsO_4$		
Sarkinite	$(MnOH)MnAsO_4$	2·0017 : 1 : 1·5154;	62° 13½′

Phosphates (and arsenates) of magnesium (calcium), iron and manganese containing fluorine (also hydroxyl). Formula R_2FPO_4 or $(RF)RPO_4$, etc.

WAGNERITE.

Monoclinic. Axes, see above. Crystals sometimes large and coarse. Also massive.

Cleavage: *a* (100), *m* (110) imperfect; *c* (001) in traces. Fracture uneven and splintery. Brittle. H. = 5–5·5. G. = 3·07–3·14. Luster vitreous. Streak white. Color yellow, of different shades; often grayish, also flesh-red, greenish. Translucent. Optically +. 2V = 26° (approx.). α = 1·569. β = 1·570. γ = 1·582.

Comp. — A fluo-phosphate of magnesium, $(MgF)MgPO_4$ or $Mg_3P_2O_8.MgF_2$ = Phosphorus pentoxide 43·8, magnesia 49·3, fluorine 11·8 = 104·9, deduct (O = 2F) 4·9 = 100. A little calcium replaces part of the magnesium.

Pyr., etc. — B.B. in the forceps fuses at 4 to a greenish gray glass; moistened with sulphuric acid colors the flame bluish green. With borax reacts for iron. On fusion with soda effervesces, but is not completely dissolved; gives a faint manganese reaction. Reacts for fluorine. Soluble in nitric and hydrochloric acids. With sulphuric acid evolves fumes of hydrofluoric acid.

Obs. — *Wagnerite* (in small highly modified crystals) occurs in the valley of Höllengraben, near Werfen, in Salzburg, Austria. *Kjerulfine* (massive, cleavable; also in coarse crystals) is from Kjörrestad, near Bamle, Norway.

Spodiosite. A calcium fluo-phosphate, perhaps $(CaF)CaPO_4$. In flattened prismatic orthorhombic crystals. G. = 2·94. Color ash-gray. From the Krangrufva, Wermland, and Nordmark, Sweden.

TRIPLITE.

Monoclinic. Massive, imperfectly crystalline. Cleavage: unequal in two directions perpendicular to each other, one much the more distinct. Fracture small conchoidal. H. = 4–5·5. G. = 3·44–3·8. Luster resinous, inclining to adamantine. Color brown or blackish brown. Streak yellowish gray or brown. Subtranslucent to opaque. Optically +. Mean index from 1·66–1·68.

Comp. — $(RF)RPO_4$ or $R_3P_2O_8.RF_2$ with R = Fe and Mn, also Ca and Mg. The ratio varies widely from Fe : Mn = 1 : 1 to 2 : 1 (zwieselite); 1 : 2; 1 : 7.

Talktriplite is a variety from Horrsjöberg, Sweden; contains magnesium and calcium in large amount.

Pyr., etc. — B.B. fuses easily at 1·5 to a black magnetic globule; moistened with sulphuric acid colors the flame bluish green. With borax in O.F. gives an amethystine-colored glass (manganese); in R.F. a strong reaction for iron. With soda reacts for manganese. With sulphuric acid evolves hydrofluoric acid. Soluble in hydrochloric acid.

Obs. — Found by Alluaud at Limoges in France; Helsingfors, Finland; Stoneham, Me.; Branchville, Conn.; from Reagan mining district, White Pine Co., Nev. *Zwieselite*, a clove-brown variety, is from Rabenstein, near Zwiesel in Bavaria.

GRIPHITE. A problematical phosphate related to triplite occurring in embedded reniform masses. From the Riverton lode near Harney City, Pennington Co., S. D.

Phosphoferrite. $H_6\overset{II}{R}_9(PO_4)_8$: R = Fe, Mn, Ca, Mg. Columnar. White to yellow or pale green. H. = 4–5. G. = 3·16. Habendorf, Bavaria.

Triploidite. Like triplite, but with the F replaced by (OH). Monoclinic. Commonly in crystalline aggregates. Fibrous to columnar. H. = 4·5–5. G. = 3·697. Color yellowish to reddish brown. Optically +. $\beta = 1·726$. From Branchville, Fairfield Co., Conn.

Adelite. $(MgOH)CaAsO_4$. Monoclinic. Axes, see p. 600; also massive. H. = 5. G. = 3·74. Color gray or grayish yellow. Optically +. Mean index, 1·67. From Nordmark and Långban, Sweden.

Tilasite. Like adelite, but contains fluorine. Monoclinic. Optically –. $\beta = 1·660$. From Långban, Sweden, and Kajlidongri, Jhabua, India.

Sarkinite. $(MnOH)MnAsO_4$. In monoclinic crystals; also in spherical forms. G. = 4·17. Color rose-red, flesh-red, reddish yellow. From the iron-manganese mines of Pajsberg, Sweden. *Polyarsenite* and *Xantharsenite* from the Sjö mine, Grythytte parish, Orebro, Sweden, and *Chondrasenite* from Pajsberg, Sweden, are essentially the same.

Trigonite. $Pb_3MnH(AsO_3)_3$. Monoclinic-clinohedral. In small wedge-shaped crystals. H. = 2–3. Perfect cleavage || (010). Color sulphur-yellow. $\alpha = 2·08$. $\gamma = 2·16$. Ax. pl. || (010). From Långban, Sweden.

Herderite. A fluo-phosphate of beryllium and calcium, $Ca[Be(F,OH)]PO_4$. In prismatic crystals, monoclinic with complex twinning. H. = 5. G. = 2·99–3·01. Luster vitreous. Color yellowish and greenish white. Optically –. $\beta = 1·612$. From the tin mines of Ehrenfriedersdorf, Saxony; from Epprechtstein, Bavaria; also at Stoneham, Auburn, Hebron, and Paris, Me.

Hamlinite. A basic phosphate of aluminium, and strontium. In colorless rhombohedral crystals. H. = 4·5. G. = 3·16–3·28. Optically +. $\omega = 1·620$. Occurs with herderite, bertrandite, etc., at Stoneham, Me. In the diamond sands of Diamantina, Brazil. Found also in Binnental, Switzerland (originally thought to be a new species and named *bowmannite*).

Plumbogummite. A basic phosphate of lead and aluminium. In chemical group with *hamlinite*. Resembles drops or coatings of gum; as incrustations. Color yellowish, brownish. From Roughten Gill, Cumberland, England. *Hitchcockite* from Canton mine, Ga., is closely identical. The material from Huelgoet, Brittany, France, is a mixture.

Florencite. A basic phosphate of aluminium and the cerium metals, closely analogous to hamlinite to which it is related in form. $3Al_2O_3.Ce_2O_3.2P_2O_5.6H_2O$. Hexagonal, rhombohedral. Habit rhombohedral. Basal cleavage. H. = 5. G. = 3·58. Color pale yellow. Infusible. Found in sands from near Ouro Preto and Diamantina, Minas Geraes, Brazil.

Georceixite. A basic phosphate of aluminium and barium (with smaller amounts of calcium and cerium). $BaO.2Al_2O_3.P_2O_5.5H_2O$. Microcrystalline, in rolled pebbles. H. = 6. G. = 3·1. Color brown and white. Refractive index, 1·63. From the diamond sands of Minas Geraes, Brazil. *Geraesite* is similar but more acidic in composition.

Crandallite. $2CaO.4Al_2O_3.2P_2O_5.10H_2O$. In compact to cleavable masses. Microscopically fibrous. Color white to light gray. Indices, 1·58–1·60. Found at Brooklyn mine near Silver City, Utah.

Harttite. A basic phosphate and sulphate of aluminium and strontium, $(Sr,Ca)O.2Al_2O_3.P_2O_5.SO_3.5H_2O$. Hexagonal. Usually microcrystalline as rolled pebbles. H. = 4·5–5. G. = 3·2. Color flesh-red. From the diamond sands of Minas Geraes, Brazil.

Ježekite. A fluo-phosphate of lime, soda, and alumina, $Na_4CaAl(AlO)(F,OH)_4(PO_4)_2$. Monoclinic. H. = 4·5. G. = 2·94. Cleavage perfect (100); imperfect (001). Indices, 1·55–1·59. Colorless or white. From Ehrenfriedersdorf, Saxony.

Lacroixite. A fluo-phosphate of soda, lime, manganese oxide, and alumina. $Na_4(Ca,Mn)_4Al_3(F,OH)_4P_3O_{16}.2H_2O$. Probably monoclinic. Pyramidal cleavage. H. = 4·1. G. = 3·13. Color pale yellow or green. Found at Ehrenfriedersdorf, Saxony.

Durangite. A fluo-arsenate of sodium and aluminium, $Na(AlF)AsO_4$. In monoclinic crystals. G. = 3·94–4·07. Color orange-red. Mean index, 1·673. From Durango, Mexico.

AMBLYGONITE. Hebronite.

Triclinic. Crystals large and coarse; forms rarely distinct. Usually cleavable to columnar and compact massive. Polysynthetic twinning lamellæ common.

Cleavage: *c* (001) perfect, with pearly luster; *a* (100) somewhat less so, vitreous; *e* ($0\bar{2}1$) sometimes equally distinct; *M* ($1\bar{1}0$) difficult; *ca* (001) ∧ (100) = 75° 30′, *ce* (001) ∧ ($0\bar{2}1$) = 74° 40′, *cM* (001) ∧ ($1\bar{1}0$) = 92° 20′. Fracture uneven to subconchoidal. Brittle. H. = 6. G. = 3·01–3·09. Luster vitreous to greasy, on *c* (001) pearly. Color white to pale greenish, bluish, yellowish, grayish or brownish white. Streak white. Subtransparent to translucent. Optically –. α = 1·579. β = 1·593. γ = 1·597.

Comp. — A fluo-phosphate of aluminium and lithium, $Li(AlF)PO_4$ or $AlPO_4.LiF$ = Phosphorus pentoxide 47·9, alumina 34·4, lithia 10·1, fluorine 12·9 = 105·3, deduct (O = 2F) 5·3 = 100. Sodium often replaces part of the lithium, and hydroxyl part of the fluorine.

Pyr., etc. — In the closed tube yields water, which at a high heat is acid and corrodes the glass. B.B. fuses easily (at 2) with intumescence, and becomes opaque white on cooling. Colors the flame yellowish red with traces of green; the Hebron variety gives an intense lithia-red; moistened with sulphuric acid gives a bluish green to the flame. With borax and salt of phosphorus forms a transparent colorless glass. In fine powder dissolves easily in sulphuric acid, more slowly in hydrochloric acid.

Diff. — Distinguished by its easy fusibility and by yielding a red flame B.B., from feldspar, barite, calcite, etc.; also by the acid water in the tube from spodumene.

Obs. — Occurs near Penig in Saxony; Arendal, Norway; Montebras, Creuze, France. In the United States, in Me., at Hebron; also at Paris, Peru, etc.; Branchville, Conn., Pala, San Diego Co., Cal.

The name *amblygonite* is from *ἀμβλύς, blunt*, and *γόνυ, angle*.

Fremontite. Natramblygonite. Natromontebrasite. $(Na,Li)Al(OH,F)PO_4$. Monoclinic. Crystals coarse with rough faces. Three cleavages. Usually in cleavage masses. Polysynthetic twinning shown under microscope. H. = 5·5. G. = 3·04. Luster vitreous to greasy. Color, grayish white to white. Translucent to opaque. Optically –. Bisectrix nearly normal to basal cleavage. Easily fusible to a white enamel with strong sodium flame color. From a pegmatite near Canon City, Fremont County, Col.

B. Basic Phosphates

This section includes a series of well-characterized basic phosphates, a number of which fall into the Olivinite Group. Acid phosphates are represented by one species only, the little known monetite, probably $HCaPO_4$, see p. 606.

Olivenite Group. Orthorhombic

		$a : b : c$
Olivenite	$Cu_2(OH)AsO_4$	0·9396 : 1 : 0·6726
Libethenite	$Cu_2(OH)PO_4$	0·9601 : 1 : 0·7019
Adamite	$Zn_2(OH)AsO_4$	0·9733 : 1 : 0·7158
Descloizite	$(Pb,Zn)_2(OH)VO_4$	$a : b : c$ = 0·6368 : 1 : 0·8045 or $\frac{3}{2}a : b : c$ = 0·9552 : 1 : 0·8045
Cuprodescloizite	$(Pb,Zn,Cu)_2(OH)VO_4$	

The OLIVENITE GROUP includes several basic phosphates, arsenates, etc., of copper, zinc, and lead, with the general formula $(ROH)RPO_4,(ROH)RAsO_4$, etc. They crystallize in the orthorhombic system with similar form. It is to be noted that this group corresponds in a measure to the monoclinic Wagnerite Group, p. 600, which also includes basic members.

OLIVENITE.

Orthorhombic. Axes $a : b : c = 0·9396 : 1 : 0·6726$.

mm''', $110 \wedge 1\bar{1}0$ = 86° 26'. *ee'*, $011 \wedge 0\bar{1}1$ = 67° 51'.
vv', $101 \wedge \bar{1}01$ = 71° 11½'. *ve*, $101 \wedge 011$ = 47° 34'.

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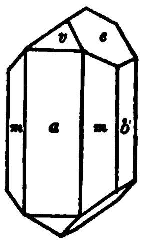

Crystals prismatic, often acicular. Also globular and reniform, indistinctly fibrous, fibers straight and divergent, rarely irregular; also curved lamellar and granular.

Cleavage: *m* (110), *b* (010), *e* (011) in traces. Fracture conchoidal to uneven. Brittle. H. = 3. G. = 4·1–4·4. Luster adamantine to vitreous; of some fibrous varieties pearly. Color various shades of olive-green, passing into leek-, siskin-, pistachio-, and blackish green; also liver- and wood-brown; sometimes straw-yellow and grayish white. Streak olive-green to brown. Subtransparent to opaque. Mean index, 1·83.

Var. — (*a*) *Crystallized.* (*b*) *Fibrous;* finely and divergently fibrous, of green, yellow, brown and gray, to white colors, with the surface sometimes velvety or acicular; found investing the common variety or passing into it; called *wood-copper* or *wood-arsenate.* (*c*) *Earthy;* nodular or massive; sometimes soft enough to soil the fingers.

Comp. — $Cu_3As_2O_8Cu(OH)_2$ or $4CuO.As_2O_5.H_2O$ = Arsenic pentoxide 40·7, cupric oxide 56·1, water 3·2 = 100.

Pyr., etc. — In the closed tube gives water. B.B. fuses at 2, coloring the flame bluish green, and on cooling the fused mass appears crystalline. B.B. on charcoal fuses with deflagration, gives off arsenical fumes, and yields a metallic arsenide which with soda yields a globule of copper. With the fluxes reacts for copper. Soluble in nitric acid.

Obs. — The crystallized varieties occur in Cornwall, at various mines; Tavistock, in Devonshire; in Tyrol, Austria; the Banat, Hungary; Nizhni Tagilsk in the Ural Mts.; Chile. In the United States, in Utah, at the American Eagle and Mammoth mines, Tintic district, both in crystals and *wood-copper*. The name olivenite alludes to the olive-green color.

LIBETHENITE.

Orthorhombic. Axes $a : b : c = 0·9601 : 1 : 0·7019$.

mm''', $110 \wedge 1\bar{1}0$ = 87° 40'. *ss'''*, $111 \wedge 1\bar{1}1$ = 59° 4¼'.
ee', $011 \wedge 0\bar{1}1$ = 70° 8'. *ss'*, $111 \wedge \bar{1}11$ = 61° 47½'.

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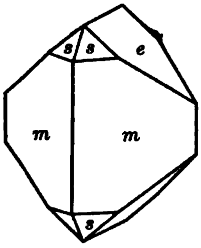

In crystals usually small, short prismatic in habit; often united in druses. Also globular or reniform and compact.

Cleavage: *a* (100), *b* (010) very indistinct. Fracture subconchoidal to uneven. Brittle. H. = 4. G. = 3·6–3·8. Luster resinous. Color olive-green, generally dark. Streak olive-green. Translucent to subtranslucent. Mean index, 1·72.

Comp. — $Cu_3P_2O_8.Cu(OH)_2$ or $4CuO.P_2O_5.H_2O$ = Phosphorus pentoxide 29·8, cupric oxide 66·4, water 3·8 = 100.

Pyr., etc. — In the closed tube yields water and turns black. B.B. fuses at 2 and colors the flame emerald-green. On charcoal with soda gives metallic copper, sometimes also an arsenical odor. Fused with metallic lead on charcoal is reduced to metallic copper, with the formation of lead phosphate, which treated in R.F. gives a crystalline polyhedral bead on cooling. With the fluxes reacts for copper. Soluble in nitric acid.

Obs. — Occurs with chalcopyrite at Libethen, near Neusohl, Hungary; at Rheinbreitenbach and Ehl on the Rhine, Germany; at Nizhni Tagilsk in the Ural Mts.; from Viel-Salm, Belgium; in small quantities in Cornwall, England. In Clifton-Morenci district, Ariz.

Tarbuttite. $Zn_3P_2O_8.Zn(OH)_2$. Triclinic. Crystals striated and rounded, frequently in sheaf-like aggregates. Perfect basal cleavage. H. = 3·7. G. = 4·1. Colorless to pale yellow, brown, red, or green. Fusible. From Broken Hill, N. W. Rhodesia.

Adamite. $Zn_3As_2O_8.Zn(OH)_2$. In small orthorhombic crystals, often grouped in crusts and granular aggregations. H. = 3·5. G. = 4·34–4·35. Color honey-yellow, violet, rose-red, green, colorless. Mean index, 1·73. From Chañarcillo, Chile; Cap Garonne, France; from Mte. Valerio, Campiglia Marittima, Italy; at the ancient zinc mines of Laurion, Greece. From Island of Thasos, Turkey. Varieties from Cap Garonne, Var, France, containing cobalt and copper have been called *cobaltoadamite* and *cuproadamite*.

Descloizite. $R_2V_2O_8.R(OH)_2$ or $4RO.V_2O_5.H_2O$; R = Pb, Zn chiefly, and usually in the ratio 1 : 1 approx. In small orthorhombic crystals, often drusy; also massive, fibrous radiated with mammillary surface. H. = 3·5. G. = 5·9–6·2. Color cherry-red and brownish red, to light or dark brown, black. Streak orange to brownish red or yellowish gray. Mean index, 1·83.

From the Sierra de Córdoba, Argentina; Kappel in Carinthia. Abundant at Lake Valley, Sierra Co., N. M., also near Georgetown and at Magdalena; in Ariz. near Tombstone; in Yavapai Co.; at the Mammoth Gold mine, near Oracle, Pinal Co.

A massive variety, containing copper (6·5 to 9 p. c.), in crusts, and reniform masses with radiated structure, occurs in San Luis Potosi, also in a vein of argentiferous galena in Zacatecas, Mexico; it has been variously named *cuprodescloizite*, *tritochorite*, *ramirite*. A similar variety (11 p. c. CuO) occurs as an incrustation on quartz at the Lucky Cuss mine, Tombstone, Cochise Co., and in stalactites at Shattuck Arizona mine, Bisbee, Ariz. From Camp Signal, San Bernardino Co., Cal.

EUSYNCHITE may be identical with descloizite. Massive: in nodular, stalactitic forms. G. = 5·596. Color yellowish red, reddish brown, greenish. From Hofsgrund near Freiburg in Baden, Germany. The same may be true of *aræoxene* from Dahn near Nieder-Schlettenbach, Rhenish Bavaria, Germany.

Pyrobelonite. $4PbO.7MnO.2V_2O_5.3H_2O$. Orthorhombic. In small acicular crystals. Fire-red color. H. = 3·5. G. = 5·377. High index. Probably related crystallographically to descloizite. From Långban, Sweden.

DECHENITE. Composition usually accepted as PbV_2O_6. Massive, botryoidal, nodular. G. = 5·6–5·81. Color deep red to yellowish red and brownish red. From Nieder-Schlettenbach in the Lautertal, Rhenish Bavaria, Germany.

Calciovolborthite. Probably $(Cu,Ca)_3V_2O_8.(Cu,Ca)(OH)_2$. In thin green tables; also gray, fine crystalline granular. Mean index, 2·05. From Friedrichsrode, Thuringia, Germany. Minerals from Richardson, southeastern Utah, and from near Baker City, Oregon, probably belong here.

Higginsite. $CuCa(OH)AsO_4$. Orthorhombic. Small prismatic crystals. H. = 4·5. G. = 4·33. n = 1·745. Pleochroic, green, yellow-green, blue-green. From Higgins mine, Bisbee, Ariz.

Brackebuschite. Near descloizite (monoclinic?). From the State of Córdoba, Argentina.

TURANITE. A copper vanadate, $5CuO.V_2O_5.2H_2O$. Radiating fibrous. From Tyuya-Muyun, south of Andidjan, Alai Mts., Turkestan.

Psittacinite. A vanadate of lead and copper, from the Silver Star District, Mon. In thin coatings; also pulverulent. Color siskin- to olive-green.

MOTTRAMITE. A vanadate of lead and copper; possibly identical with psittacinite; in velvety black incrustations. From Mottram St. Andrew's, Cheshire, England.

Furnacite. A basic chrom-arsenate of lead and copper. In dark olive-green, small prismatic crystals. From Djocié, French Equatorial Africa.

Tsumebite. Preslite. A basic lead and copper phosphate. Orthorhombic? In small tabular crystals. H. = 3·5. G. = 6·1. Index, > 1·78. Color emerald-green. Pleochroic, blue-green to yellow-green. Easily fusible. From Tsumeb, Otavi, German S. W. Africa.

CLINOCLASITE. Aphanèse.

Monoclinic. Axes $a : b : c$ = 1·9069 : 1 : 3·8507; β = 80° 30′.

Crystals prismatic (m (110)); also elongated || b axis; often grouped in nearly spherical forms. Also massive, hemispherical or reniform; structure radiated fibrous.

Cleavage: *c* (001) highly perfect. Brittle. H. = 2·5–3. G. = 4·19–4·37. Luster: *c* pearly; elsewhere vitreous to resinous. Color internally dark verdigris-green; externally blackish blue-green. Streak bluish green. Subtransparent to translucent.

Comp. — $Cu_3As_2O_8.3Cu(OH)_2$ or $6CuO.As_2O_5.3H_2O$ = Arsenic pentoxide 30·3, cupric oxide 62·6, water 7·1 = 100.

Pyr., etc. — Same as for olivenite.

Obs. — Occurs in Cornwall, with other ores of copper. In Utah, Tintic district, at the Mammoth mine. From Collahurasi, Tarapaca, Chile. Named in allusion to the basal cleavage being oblique to the sides of the prism.

Erinite. $Cu_3As_2O_8.2Cu(OH)_2$. In mammillated crystalline groups. Color fine emerald-green. From Cornwall; also the Tintic district, Utah.

Dihydrite. $Cu_3P_2O_8.2Cu(OH)_2$. In dark emerald-green crystals (monoclinic). H. = 4·5–5. G. = 4–4·4. From Ehl near Linz on the Rhine, Germany; the Ural Mts., etc.

Pseudomalachite. In part $Cu_3P_2O_8.3Cu(OH)_2$. Massive, resembling malachite in color and structure. Indices, 1·83–1·93. From Rheinbreitenbach, Germany; Nizhni Tagilsk, Russia, etc. *Ehlite* is closely allied.

DUFRENITE. Kraurite.

Orthorhombic. Crystals rare, small, and indistinct. Usually massive, in nodules; radiated fibrous with drusy surface.

Cleavage: *a* (100), probably also *b* (010), but indistinct. H. = 3·5–4. G. = 3·2–3·4. Luster silky, weak. Color dull leek-green, olive-green, or blackish green; alters on exposure to yellow and brown. Streak siskin-green. Subtranslucent to nearly opaque. Strongly pleochroic. Indices, 1·83–1·93.

Comp. — Doubtful; in part $FePO_4.Fe(OH)_3 = 2Fe_2O_3.P_2O_5.3H_2O$ = Phosphorus pentoxide 27·5, iron sesquioxide 62·0, water 10·5 = 100.

Pyr., etc. — Same as for vivianite, but less water is given out in the closed tube. B.B. fuses easily to a slag.

Obs. — Occurs near Anglar, Dept. of Haute Vienne, France; in Germany at Hirschberg in Westphalia and from the Rothläufchen mine near Waldgirmes; St. Benigna, Bohemia; East Cornwall, England.

In the United States, at Allentown, N. J.; in Rockbridge Co., Va., in radiated coarsely fibrous masses; from Grafton, N. H. *Dufreniberaunite* is a variety intermediate in composition between *dufrenite* and *beraunite* from Hellertown, Pa.

LAZULITE.

Monoclinic: Axes $a : b : c = 0{\cdot}9750 : 1 : 1{\cdot}6483$; $\beta = 89° 14'$.

at, $100 \wedge 101 = 30° 24'$. *ee'*, $\bar{1}11 \wedge \bar{1}\bar{1}1 = 80° 20'$.
pp', $111 \wedge 1\bar{1}1 = 79° 40'$. *pe*, $111 \wedge \bar{1}11 = 82° 30'$.

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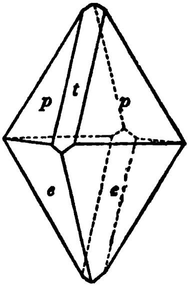

Crystals usually acute pyramidal in habit. Also massive, granular to compact.

Cleavage: prismatic, indistinct. Fracture uneven. Brittle. H. = 5–6. G. = 3·057–3·122. Luster vitreous. Color azure-blue; commonly a fine deep blue viewed along one axis, and a pale greenish blue along another. Streak white. Subtranslucent to opaque. Optically −. 2V = 69°. $\alpha = 1{\cdot}603$. $\beta = 1{\cdot}632$. $\gamma = 1{\cdot}639$.

Comp. — $RAl_2(OH)_2P_2O_8$ or $2AlPO_4.(Fe,Mg)(OH)_2$ with Fe : Mg(Ca) = 1 : 12, 1 : 6, 1 : 2, 2 : 3. For 1 : 2 the formula requires: Phosphorus pentoxide 45·4, alumina 32·6, iron protoxide 7·7, magnesia 8·5, water 5·8 = 100.

Pyr., etc. — In the closed tube whitens and yields water. In the forceps whitens, cracks open, swells up, and without fusion falls to pieces, coloring the flame bluish green. B.B. with cobalt solution the blue color of the mineral is restored. The green color of the flame is made more intense by moistening the assay with sulphuric acid. With the fluxes gives an iron glass; with soda on charcoal an infusible mass. Unacted upon by acids, retaining perfectly its blue color.

Obs. — Occurs near Werfen in Salzburg, Austria; Krieglach, in Styria; also Horrsjöberg, Sweden; from Madagascar.

Abundant with corundum at Crowder's Mt., Gaston Co., N. C.; and on Graves Mt., Lincoln Co., Ga., with cyanite, rutile, etc.

The name lazulite is derived from an Arabic word, *azul*, meaning *heaven*, and alludes to the color of the mineral.

Tavistockite. $Ca_3P_2O_8.2Al(OH)_3$. In microscopic acicular crystals, sometimes stellate groups. Color white. From Tavistock, Devonshire.

Cirrolite. Perhaps $Ca_3Al(PO_4)_3.Al(OH)_3$. Compact. G. = 3·08. Color pale yellow. Occurs at the iron mine at Westanå, in Scania, Sweden.

Arseniosiderite. $Ca_3Fe(AsO_4)_3.3Fe(OH)_3$. In yellowish brown fibrous concretions. G. = 3·520. Index, 3·83. From Romanèche, near Mâcon, France; also at Schneeberg, Saxony.

Allactite. $Mn_3As_2O_8.4Mn(OH)_2$. Monoclinic. In small brownish red prismatic crystals. Mean index, 1·786. From the Moss mine, Nordmark, and at Långban, Sweden.

Synadelphite. $2(Al,Mn)AsO_4.5Mn(OH)_2$. In prismatic crystals; also in grains. G. = 3·45–3·50. Color brownish black to black. From the Moss mine, Nordmark, Sweden.

Flinkite. $MnAsO_4.2Mn(OH)_2$. In minute orthorhombic crystals, tabular ‖ *c* (001); grouped in feather-like aggregates. G. = 3·87. Color greenish brown. From the Harstig mine, Pajsberg, Sweden.

Hematolite. Perhaps $(Al,Mn)AsO_4.4Mn(OH)_2$. In rhombohedral crystals. G. = 3·30–3·40. Color brownish red, black on the surface. Mean Index, 1·730. From the Moss mine, Nordmark, Sweden.

Retzian. A basic arsenate of the yttrium earths, manganese and calcium. In orthorhombic crystals. H. = 4. G. = 4·15. Color chocolate- to chestnut-brown. From the Moss mine, Nordmark, Sweden.

Arseniopleite. Perhaps $\overset{\text{II}}{R}_6\overset{\text{III}}{R}_2(OH)_6(AsO_4)_6$; $\overset{\text{II}}{R}$ = Mn, Ca, also Pb, Mg; $\overset{\text{III}}{R}$ = Mn, also Fe. Massive, cleavable. Color brownish red. Occurs at the Sjö mine, Grythytte parish, Sweden, with rhodonite in crystalline limestone.

Manganostibiite. Hematostibiite. Highly basic manganese antimonates. In embedded grains. Color black. *Manganostibiite* occurs at Nordmark, Sweden; *hematostibiite* is from the Sjö mine, Grythytte parish, Sweden.

Atelestite. Basic bismuth arsenate, $H_2Bi_3AsO_8$. In minute tabular crystals. G. = 6·4. Color sulphur-yellow. From Schneeberg, Saxony.

C. Normal Hydrous Phosphates, etc.

The only important group among the normal hydrous phosphates is the monoclinic VIVIANITE GROUP.

Struvite. Hydrous ammonium-magnesium phosphate. In orthorhombic-hemimorphic crystals (Fig. 323, p. 127); white or yellowish; slightly soluble. Index, 1·502. From guano deposits.

Collophanite. $Ca_3P_2O_8.H_2O$. In layers resembling gymnite or opal. Colorless or snow-white. $n = 1.59$. From the island of Sombrero, West Indies. *Monite* is similar, from the islands Mona and Moneta in the West Indies, where it is associated with *monetite*, $HCaPO_4$ occurring in yellowish white triclinic crystals.

PYROPHOSPHORITE. $Mg_2P_2O_7.4(Ca_3P_2O_8.Ca_2P_2O_7)$. Massive, earthy. Color snow-white, dull. From the West Indies.

Hopeite. Hydrous zinc phosphate, $Zn_3P_2O_8.4H_2O$. Orthorhombic. In minute prismatic crystals. Also in reniform masses. Three cleavages: *a* (100), perfect; *b* (010), good; *c* (001), poor. Crystals from Broken Hill show interbanding of two modifications, α- and β-hopeite which have the same composition but differ in their optical characters. H. = 3·2. G. = 3·0–3·1. Color grayish white. Optically −. β = 1·59. Found in cavities in calamine at the zinc mines of Moresnet, Belgium; at the Broken Hill mines, Rhodesia.

Parahopeite. $Zn_3P_2O_8.4H_2O$. Same as for hopeite. Triclinic. In tabular crystals with deep striations. Good cleavage. H. = 3·7. G. = 3·3. Colorless. Found at Broken Hill, Rhodesia.

Dickinsonite. $3R_3P_2O_8.H_2O$ with R = Mn, Fe, Na_2 chiefly, also Ca, K_2, Li_2. In tabular, pseudo-rhombohedral crystals; commonly foliated to micaceous. G. = 3·338–3·343. Color olive- to oil-green, grass-green. β = 1·662. From Branchville, Fairfield Co., Conn.

Fillowite. Formula as for dickinsonite and also from Branchville, Conn., but differing in angle. In granular crystalline masses. G. = 3·43. Color wax-yellow, yellowish to reddish brown, colorless. β = 1·672.

The three following triclinic species are related in composition and may be in crystalline form.

Roselite. $(Ca,Co,Mg)_3As_2O_8.2H_2O$. In small crystals; often in druses and spherical aggregates. G. = 3·5–3·6. Color light to dark rose-red. From Schneeberg, Saxony.

Brandtite. $Ca_2MnAs_2O_8.2H_2O$. In prismatic crystals; crystals often united in radiated groups. G. = 3·671–3·672. Colorless to white. From the Harstig mine, near Pajsberg, Sweden.

Fairfieldite. A hydrous phosphate of calcium and manganese, $Ca_2MnP_2O_8.2H_2O$. Triclinic. In prismatic crystals; usually in foliated or fibrous crystalline aggregates. G. = 3·07–3·15. Color white or greenish white to pale straw-yellow. β = 1·644. From Branchville, Fairfield Co., Conn.; Rabenstein, Bavaria (*leucomanganite*).

Messelite. $(Ca,Fe)_3P_2O_8.2\frac{1}{2}H_2O$. In minute tabular crystals. Colorless to brownish. β = 1·653. From near Messel in Hesse, Germany. Perhaps an alteration of *Anapaite* through loss of water.

Anapaite. *Tamanite.* $(Ca,Fe)_3P_2O_8.4H_2O$. Triclinic. In tabular crystals. One perfect cleavage. H. = 3·5. G. = 2·8. Color greenish white. From the limonite mines near Anapa on the Taman peninsula, Russia.

Reddingite. $Mn_3P_2O_8.3H_2O$. In orthorhombic crystals near scorodite in angle; also granular. G. = 3·102. Color pinkish white to yellowish white. Optically +. β = 1·656. From Branchville, Conn.

Palaite. Hydrous manganese phosphate, $5MnO.2P_2O_5.4H_2O$. Monoclinic? In crystalline masses. G. = 3·2. Color, flesh-pink. Indices 1·65–1·66. From Pala, San Diego Co., Cal. Derived by alteration from *lithiophilite* and alters into *hureaulite.*

Stewartite. Hydrous manganese phosphate, $3MnO.P_2O_5.4H_2O$. Triclinic? In fibers or minute crystals. G. = 2·94. Indices, 1·63–1·69. Pleochroic, colorless to yellow. Found as an alteration product of lithiophilite from Pala, Cal.

Picropharmacolite. $R_3As_2O_8.6H_2O$, with R = Ca : Mg = 5 : 1. In small spherical forms. Color white. From Riechelsdorf and Freiberg, Germany; Joplin, Mo.

Trichalcite. $Cu_3As_2O_8.5H_2O$. In radiated groups, columnar; dendritic. Color verdigris-green. From the Turginsk copper mine near Bogoslovsk, Ural Mts.

Vivianite Group. Monoclinic

Vivianite	$Fe_3P_2O_8.8H_2O$	$a : b : c = 0·7498 : 1 : 0·7015$	β = 75° 34′
Symplesite	$Fe_3As_2O_8.8H_2O$	0·7806 : 1 : 0·6812	72° 43′
Bobierrite	$Mg_3P_2O_8.8H_2O$		
Hœrnesite	$Mg_3As_2O_8.8H_2O$		
Erythrite	$Co_3As_2O_8.8H_2O$	0·75 : 1 : 0·70	75°
Annabergite	$Ni_3As_2O_8.8H_2O$		
Cabrerite	$(Ni,Mg)_3As_2O_8.8H_2O$		
Köttigite	$Zn_3As_2O_8.8H_2O$		

The VIVIANITE GROUP includes hydrous phosphates of iron, magnesium, cobalt, nickel and zinc, all with eight molecules of water. The crystallization is monoclinic, and the angles, so far as known, correspond closely.

VIVIANITE.

Monoclinic. Crystals prismatic (*mm'''* 110 ∧ 1$\bar{1}$0 = 71° 58'); often in stellate groups. Also reniform and globular; structure divergent, fibrous, or earthy; also incrusting.

Cleavage: *b* (010) highly perfect; *a* (100) in traces; also fracture fibrous nearly ⊥ *c* axis. Flexible in thin laminæ; sectile. H. = 1·5 – 2. G = 2·58 – 2·68. Luster, *b* (010) pearly or metallic pearly; other faces vitreous. Colorless when unaltered, blue to green, deepening on exposure. Streak colorless to bluish white, changing to indigo-blue and to liver-brown. Transparent to translucent; opaque after exposure. Pleochroism strong; *X* = cobalt-blue, *Y* and *Z* = pale greenish yellow. Optically +. α = 1·581. β = 1·604. γ = 1·636.

Comp. — Hydrous ferrous phosphate, $Fe_3P_2O_8.8H_2O$ = Phosphorus pentoxide 28·3, iron protoxide 43·0, water 28·7 = 100.

Many analyses show the presence of iron sesquioxide due to alteration.

Pyr., etc. — In the closed tube yields neutral water, whitens, and exfoliates. B.B. fuses at 1·5, coloring the flame bluish green, to a grayish black magnetic globule. With the fluxes reacts for iron. Soluble in hydrochloric acid.

Obs. — Occurs associated with pyrrhotite and pyrite in copper and tin veins; sometimes in narrow veins with gold, traversing graywacke; both friable and crystallized in beds of clay, and sometimes associated with limonite, or bog iron ore; often in cavities of fossils or buried bones.

Occurs at St. Agnes and elsewhere in Cornwall, England; at Bodenmais, Germany; the gold mines of Verespatak in Transylvania. From Ashio, Shimotsuke, Japan. A variety from the Kertsch and Taman peninsulas, South Russia, that contains small quantities of manganese and magnesium has been called *paravivianite*. The earthy variety, sometimes called *blue iron-earth* or *native Prussian blue* (*Fer azuré*), occurs in Greenland, Carinthia, Guatemala, Bolivia, Victoria, Australia, etc.

In North America, in N. J., at Allentown, Monmouth Co., both crystallized, in nodules, and earthy; at Mullica Hill, Gloucester Co. (*mullicite*), in cylindrical masses. In Va., in Stafford Co. In Ky., near Eddyville. In Col. at Leadville; in Idaho, at Silver City. In Canada, with limonite at Vaudreuil.

Symplesite. Probably $Fe_3As_2O_8.8H_2O$. In small prismatic crystals and in radiated spherical aggregates. G. = 2·957. Color pale indigo, inclined to celandine-green. From Lobenstein, Germany; Hüttenberg, Carinthia.

Bobierrite. $Mg_3P_2O_8.8H_2O$. In aggregates of minute crystals; also massive. Colorless to white. From the guano of Mexillones, on the Chilian coast. *Hautefeuillite* is like bobierrite, but contains calcium. Monoclinic. Index 1·52. From Bamle, Norway.

Hœrnesite. $Mg_3As_2O_8.8H_2O$. In crystals resembling gypsum; also columnar; stellar-foliated. Color snow-white. From the Banat, Hungary.

ERYTHRITE. Cobalt bloom.

Monoclinic. Crystals prismatic and vertically striated. Also in globular and reniform shapes, having a drusy surface and a columnar structure; sometimes stellate. Also pulverulent and earthy, incrusting.

Cleavage: *b* (010) highly perfect. Sectile. H. = 1·5–2·5; least on *b*. G. = 2·948. Luster of *b* pearly; other faces adamantine to vitreous; also dull, earthy. Color crimson- and peach-red, sometimes gray. Streak a little paler than the color. Transparent to subtranslucent. Strongly pleochroic. Optically –. α = 1·626. β = 1·661. γ = 1·699.

Comp. — Hydrous cobalt arsenate, $Co_3As_2O_8.8H_2O$ = Arsenic pentoxide 38·4, cobalt protoxide 37·5, water 24·1 = 100. The cobalt is sometimes replaced by nickel, iron, and calcium.

Pyr., etc. — In the closed tube yields water at a gentle heat and turns bluish; at a higher heat gives off arsenic trioxide which condenses in crystals on the cool glass, and the residue has a dark gray or black color. B.B. in the forceps fuses at 2 to a gray bead, and colors the flame light blue (arsenic). B.B. on charcoal gives an arsenical odor, and fuses to a dark gray arsenide, which with borax gives the deep blue color characteristic of cobalt. Soluble in hydrochloric acid, giving a rose-red solution.

Obs. — Occurs at Schneeberg in Saxony, in micaceous scales; Wolfach in Baden; Modum in Norway. From the Veta Rica mine, Sierra Mojada, Coahuila, Mexico; Chile.

In the United States, in Pa., sparingly near Philadelphia; in Nev., at Lovelock's station. In Cal. In crystals from Cobalt, Canada. Named from *ἐρυθρός, red*.

Annabergite. $Ni_3As_2O_8.8H_2O$. Monoclinic. In capillary crystals; also massive and disseminated. Color fine apple-green. Optically −. Mean index, 1·68. From Allemont in Dauphiné, France; Annaberg, Schneeberg and Riechelsdorf, Germany; in Col.; Nev.; Cobalt, Ontario, Canada.

Cabrerite. $(Ni,Mg)_3As_2O_8.8H_2O$. Like erythrite in habit. Also fibrous, radiated; reniform, granular. Color apple-green. From the Sierra Cabrera, Spain; at Laurion, Greece.

Köttigite. Hydrous zinc arsenate, $Zn_3As_2O_8.8H_2O$. Massive, or in crusts. Color light carmine- and peach-blossom-red. Occurs with smaltite at the cobalt mine Daniel, near Schneeberg, Germany.

Rhabdophanite. Scovillite. A hydrous phosphate of the cerium and yttrium metals. Massive, small mamillary; as an incrustation. G. = 3·94–4·01. Color brown, pinkish or yellowish white. *Rhabdophanite* is from Cornwall; *Scovillite* is from the Scoville (limonite) ore bed in Salisbury, Conn.

Churchite. A hydrous phosphate of cerium and calcium. As a thin coating of minute crystals. G. = 3·14. Color pale smoke-gray tinged with flesh-red. From Cornwall, England.

Uvanite. $2UO_3.3V_2O_5.15H_2O$. Orthorhombic. Fine granular. Two pinacoidal cleavages. Color brownish yellow. Indices, 1·82–2·06. Found disseminated in rocks near Temple Rock, 45 miles southwest of Greenriver, Utah.

Ferganite. $U_3(VO_4)_2.6H_2O$. In scales. Color sulphur-yellow. From province of Fergana, Russian Turkestan.

Fernandinite. $CaO.V_2O_4.5V_2O_5.14H_2O$. Massive. Color dull green. Readily soluble in acids, partly soluble in water. Found at Minasragra, Peru.

Pascoite. Hydrous calcium vanadate, possibly $2CaO.3V_2O_5.11H_2O$. Monoclinic. In grains. H. = 2·5. G. = 2·46. Color orange. Streak yellow. Indices, 1·77–1·83. Easily fusible. Soluble in water. Found at Minasragra, Province of Pasco, Peru.

Pintadoite. Hydrous calcium vanadate, $2CaO.V_2O_5.9H_2O$. As an efflorescence. Color green. Found coating surfaces of sandstone in Canyon Pintado, Utah.

SCORODITE.

Orthorhombic. Axes $a : b : c = 0·8658 : 1 : 0·9541$.

dd', $120 \wedge \bar{1}20 = 60° 1'$. *pp''*, $111 \wedge \bar{1}11 = 111° 6'$.
pp', $111 \wedge \bar{1}11 = 77° 8'$. *pp'''*, $111 \wedge 1\bar{1}1 = 65° 20'$.

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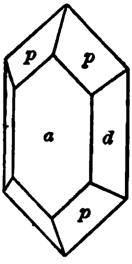


Habit octahedral, also prismatic. Also earthy, amorphous.

Cleavage: *d* (120) imperfect; *a* (100), *b* (010) in traces. Fracture uneven. Brittle. H. = 3·5–4. G. = 3·1–3·3. Luster vitreous to subadamantine and subresinous. Color pale leek-green or liver-brown. Streak white. Subtransparent to translucent. Mean index, 1·84.

Comp. — Hydrous ferric arsenate, $FeAsO_4.2H_2O$ = Arsenic pentoxide 49·8, iron sesquioxide 34·6, water 15·6 = 100.

Pyr., etc. — In the closed tube yields neutral water and turns yellow. B.B. fuses easily, coloring the flame blue. B.B. on charcoal gives arsenical fumes, and with soda a black magnetic scoria. With the fluxes reacts for iron. Soluble in hydrochloric acid.

Obs. — Often associated with arsenopyrite. From Schwarzenberg, Saxony; Dernbach, Nassau, Germany; Lölling, Carinthia; Schlaggenwald, Bohemia; Nerchinsk, Siberia, in fine crystals; leek-green, in the Cornish mines. From Congo Free State. From Obira, Japan.

Occurs near Edenville, N. Y., with arsenopyrite; in Utah, Tintic district, at the Mammoth mine on enargite. As an incrustation on siliceous sinter of the Yellowstone geysers. From Cobalt, Ontario, Canada.

Named from *σκόροδον, garlic*, alluding to the odor before the blowpipe.

Vilateite. Hydrous iron phosphate with a little manganese. Monoclinic. H. = 3–4. G. = 2·75. Color violet. Index, 1·74. Found in pegmatite at La Vilate near Chanteloube, Haute Vienne, France.

Purpurite. $2(Fe,Mn)PO_4.H_2O$. Orthorhombic(?). In small irregular masses. Two cleavages at right angles. H. = 4–4·5. G. = 3·4. Color deep red or reddish purple. Refractive index, 1·60–1·65. Fusible. Found at Kings Mt., Gaston Co., N. C., sparingly from Pala, San Diego Co., Cal., Hill City, S. D., and Branchville, Conn.

Strengite. $FePO_4.2H_2O$. Crystals rare; in habit and angle near scorodite; generally in spherical and botryoidal forms. G. = 2·87. Color pale red. Optically +. β = 1·72. From iron mines near Giessen, Germany; also in Rockbridge Co., Va., with dufrenite; from Pala, Cal.

Phosphosiderite. $2FePO_4.3\frac{1}{2}H_2O$. An iron phosphate near strengite, but with $3\frac{1}{2}H_2O$. Color red. Index 1·73. From the Siegen mining district, Germany; from Sardinia.

Barrandite. $(Al,Fe)PO_4.2H_2O$. In spheroidal concretions, color pale shades of gray. Index, 1·57. From Bohemia.

Variscite. $AlPO_4.2H_2O$. Orthorhombic. Commonly in crystalline aggregates and incrustations with reniform surface. Color green. Optically –. β = 1·556. Strongly pleochroic. From Messbach in Saxon Voigtland; Montgomery Co., Ark., on quartz; in nodular masses from Tooele Co., Utah (*Utahlite*); crystalized from Lucin, Utah.

Lucinite. Comp. same as for *variscite*, $AlPO_4.2H_2O$. Orthorhombic. Octahedral habit. Also compact, massive. H. = 5. G. = 2·52. Color green. Indices, 1·56–1·59. Found with *variscite* at Utahlite Hill, near Lucin, Boxelder Co., Utah.

Callainite. $AlPO_4.2\frac{1}{2}H_2O$. Massive; wax-like. Color apple- to emerald-green. From a Celtic grave in Lockmariaquer, Brittany.

Zepharovichite. $AlPO_4.3H_2O$. Crystalline to compact. Color yellowish or grayish white. From Trenic in Bohemia.

Palmerite. $HK_2Al_2(PO_4)_3.7H_2O$. Amorphous, pulverulent. Color white. Occurs as a stratum in a guano deposit on Mte. Alburno, Salerno, Italy.

Rosiérésite. A hydrous phosphate of aluminium with lead and copper. In stalactites. G. = 2·2. Color yellow to brown. Index, 1·5. Isotropic. Infusible. Found in abandoned copper mine at Rosiéres, Tarn, France.

Koninckite. $FePO_4.3H_2O$. In small spherical aggregates of radiating needles. Color yellow. From Richelle, Belgium.

Sicklerite. A hydrous iron-manganese phosphate with lithia, $Fe_2O_3.6MnO.4P_2O_5.3(Li,H)_2O$. In cleavable masses. G. = 3·45. Color dark brown. Indices, 1·71–1·75. Pleochroic, yellow to orange-red. Bx_a perpendicular to cleavage. Fusible, giving lithium flame. From Pala, Cal.

Salmonsite. A hydrous iron-manganese phosphate, $Fe_2O_3.9MnO.4P_2O_5.14H_2O$. Cleavable fibrous masses. G. = 2·88. Color buff. Indices, 1·65–1·67. Found at Pala, Cal., as alteration of *hureaulite*.

Acid Hydrous Phosphates, etc.

PHARMACOLITE.

Monoclinic. Crystals rare. Commonly in delicate silky fibers; also botryoidal, stalactitic.

Cleavage: *b* (010) perfect. Fracture uneven. Flexible in thin laminæ.

H. = 2–2·5. G. = 2·64–2·73. Luster vitreous; on *b* (010) inclining to pearly. Color white or grayish; frequently tinged red. Streak white. Translucent to opaque. Optically –. $\alpha = 1{\cdot}583$. $\beta = 1{\cdot}589$. $\gamma = 1{\cdot}594$.

Comp. — Probably $HCaAsO_4.2H_2O$ = Arsenic pentoxide 53·3, lime 25·9, water 20·8 = 100.

Obs. — Found with arsenical ores of cobalt and silver, also with arsenopyrite; at Andreasberg in the Harz Mts., Germany; Riechelsdorf in Hesse, Germany; Joachimstal in Bohemia, Markirch, Alsace, etc. Named from φάρμακον, *poison*.

Haidingerite. $HCaAsO_4.H_2O$. In minute crystal aggregates, botryoidal and drusy. G. = 2·848. Color white. Index, 1·67. From Joachimstal, Bohemia, with pharmacolite.

Wapplerite. $HCaAsO_4.3\frac{1}{2}H_2O$. In minute crystals; also in incrustations. Colorless to white. Found with pharmacolite at Joachimstal, Bohemia.

Brushite. $HCaPO_4.2H_2O$. In small slender monoclinic prisms; concretionary massive. Colorless to pale yellowish. $\beta = 1{\cdot}545$. Occurs in guano. **Metabrushite,** similarly associated, is $2HCaPO_4.3H_2O$. *Stoffertite* is a mineral similar to brushite but said to contain a little more water. From guano deposits on the island of Mona, West Indies.

Martinite. $H_2Ca_5(PO_4)_4.\frac{1}{2}H_2O$. From phosphorite deposits (from guano) in the island of Curacoa, West Indies.

Hewettite. $CaO.3V_2O_5.9H_2O$. In microscopic needles. G. = 2·5–2·6. Color deep red. Pleochroic, light orange-yellow to red. On heating loses water changing color through shades of brown to a bronze. Easily fusible. Found as an alteration of *patronite* at Minasragra, Peru. Also observed from Paradox Valley, Col.

Metahewettite. Comp. same as for *hewettite*. In minute tabular orthorhombic crystals. On heating loses water changing from dark red to yellow-brown. From Paradox Valley, Col., and at Thompson's, Utah.

Newberyite. $HMgPO_4.3H_2O$. In white orthorhombic crystals. Index, 1·52. From guano of Skipton Caves, Victoria. **Hannayite,** from same locality, is a hydrous phosphate of ammonium and magnesium. **Schertelite,** $Mg(NH_4)_2H_2(PO_4)_2.4H_2O$. Occurs in small tabular crystals in hot guano deposits near Skipton, southwest of Ballarat, Australia.

Stercorite. Microcosmic salt. $HNa(NH_4)PO_4.4H_2O$. In white crystalline masses and nodules in guano.

Hureaulite. $H_2Mn_5(PO_4)_4.4H_2O$. In short prismatic crystals (monoclinic). Also massive, compact, or imperfectly fibrous. Color yellowish, orange-red, rose, grayish. Optically –. $\beta = 1{\cdot}654$. From Limoges, commune of Huréaux, France. In the United States, at Branchville, Conn.; Pala, Cal.

Forbesite. $H_2(Ni,Co)_2As_2O_8.8H_2O$. Structure fibro-crystalline. Color grayish white. From Atacama, Chile.

FERRAZITE. $3(Ba,Pb)O.2P_2O_5.8H_2O$. A "fava" found in the diamond sands of Brazil. Color dark yellowish white. G. = 3·0–3·3.

Basic Hydrous Phosphates, etc.

Isoclasite. $Ca_3P_2O_8.Ca(OH)_2.4H_2O$. In minute white crystals; also columnar. From Joachimstal, Bohemia.

Hemafibrite. $Mn_3As_2O_8.3Mn(OH)_2.2H_2O$. Commonly in spherical radiated groups. Color brownish red to garnet-red, becoming black. From the Moss mine, Nordmark, Sweden.

EUCHROITE.

Orthorhombic. Habit prismatic *mm'''* 110 ∧ 1$\bar{1}$0 = 62° 40′. Cleavage: *m* (110), *n* (011) in traces. Fracture small conchoidal to uneven. Rather brittle. H. = 3·5–4. G. = 3·389. Luster vitreous. Color bright emerald- or leek-green. Transparent to translucent. Mean index, 1·70.

Comp. — $Cu_3As_2O_8.Cu(OH)_2.6H_2O$ = Arsenic pentoxide 34·2, cupric oxide 47·1, water 18·7 = 100.

Obs. — Occurs in quartzose mica slate at Libethen in Hungary, in crystals of considerable size, having much resemblance to dioptase. Named from ευχροα, *beautiful color*.

Conichalcite. Perhaps $(Cu,Ca)_3As_2O_8.(Cu,Ca)(OH)_2.\frac{1}{2}H_2O$. Orthorhombic. Usually reniform and massive, resembling malachite. Color pistachio-green to emerald-green From Andalusia, Spain; Maya-Tass, Akmolinsk, Siberia (crystals); Tintic district, Utah.

Bayldonite. $(Pb,Cu)_3As_2O_8.(Pb,Cu)(OH)_2.H_2O$. In mamillary concretions, drusy. Color green. From Cornwall, England.

Tagilite. $Cu_3P_2O_8.Cu(OH)_2.2H_2O$. In reniform or spheroidal concretions; earthy. Color verdigris- to emerald-green. From the Ural Mts.

Leucochalcite. Probably $Cu_3As_2O_8.Cu(OH)_2.2H_2O$. In white, silky acicular crystals. From the Wilhelmine mine in the Spessart, Germany.

Barthite. $3ZnO.CuO.3As_2O_5.2H_2O$. In small monoclinic (?) crystals. H. = 3. G. = 4·19. Color grass-green. Found in druses of a dolomite at Guchab, Otavi, German Southwest Africa.

Volborthite. A hydrous vanadate of copper, barium, and calcium. In small six-sided tables; in globular forms. . Color olive-green, citron-yellow. Index, 1·90. From the Ural Mts.

Hügelite. A hydrous lead-zinc vanadate. Monoclinic. In microscopic hair-like crystals. Color orange-yellow to yellow-brown. From Reichenbach near Lahr, Baden, Germany.

Cornwallite. $Cu_3As_2O_8.2Cu(OH)_2.H_2O$. Massive, resembling malachite. Color emerald-green. From Cornwall, England.

Tyrolite. Tirolit. Perhaps $Cu_3As_2O_8.2Cu(OH)_2.7H_2O$. Usually in fan-shaped crystalline groups; in foliated aggregates; also massive. Cleavage perfect, yielding soft thin flexible laminæ. Color pale green inclining to sky-blue. Index, 1·70. From Libethen, Hungary; Nerchinsk, Siberia; Falkenstein, Tyrol; etc. In the United States, in the Tintic district, Utah. Some analyses yield $CaCO_3$, usually regarded as an impurity, but it may be essential.

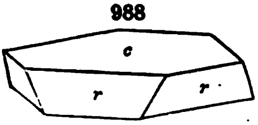
Spencerite. $Zn_3(PO_4)_2.Zn(OH)_2.3H_2O$. Monoclinic. In radiating and reticulated crystals. Cleavages parallel to three pinacoids. Color white. G. = 3·12. H. = 2·7. β = 1·61. Optically −. From Hudson Bay Mine, Salmo, B. C.

Hibbenite. $2Zn_3(PO_4)_2.Zn(OH)_2.6\frac{1}{2}H_2O$. Orthorhombic. Tabular parallel to *a* (100). Cleavages parallel to three pinacoids. Color white. G. = 3·21. H. = 3·7. Optically −. From Hudson Bay Mine, Salmo, British Columbia.

CHALCOPHYLLITE.

Rhombohedral. Axis *c* = 2·761. *cr* 0001 ∧ 10$\bar{1}$1 = 72° 2′.

988



In tabular crystals; also foliated massive; in druses.

Cleavage: *c* (0001) highly perfect; *r* (10$\bar{1}$1) in traces. H. = 2. G. = 2·4–2·66. Luster of *c* pearly; of other faces vitreous or subadamantine. Color emerald- or grass-green to verdigris-green. Streak somewhat paler than the color. Transparent to translucent. Optically −. ω = 1·632. ϵ = 1·575.

Comp. — A highly basic arsenate of copper; formula uncertain, perhaps $7CuO.As_2O_5.14H_2O$.

Pyr., etc. — In the closed tube decrepitates, yields much water, and gives a residue of olive-green scales. In other respects like olivenite. Soluble in nitric acid, and in ammonia.

Obs. — From the copper mines near Redruth in Cornwall; at Sayda, Saxony; Moldawa in the Banat, Hungary; from Chile. In the United States, in the Tintic district, Utah; Bisbee, Ariz.

Veszelyite. A hydrous phospho-arsenate of copper and zinc, formula uncertain. Occurs as a greenish blue crystalline incrustation at Morawitza, in the Banat, Hungary.

WAVELLITE.

Orthorhombic. Axes *a* : *b* : *c* = 0·5049 : 1 : 0·3751. Crystals rare. Usually in aggregates, hemispherical or globular with crystalline surface, and radiated structure.

Cleavage: *p* (101) and *b* (010) rather perfect. Fracture uneven to subconchoidal. Brittle. H. = 3·25–4. G. = 2·316–2·337. Luster vitreous, inclining to pearly and resinous. Color white, passing into yellow, green, gray, brown, and black. Streak white. Translucent. Mean index, 1·526.

Comp. — $4AlPO_4.2Al(OH)_3.9H_2O$ = Phosphorus pentoxide 35·2, alumina 38·0, water 26·8 = 100. Fluorine is sometimes present, up to 2 p. c.

Pyr., etc. — In the closed tube gives off much water, the last portions of which may react acid (fluorine). B.B. in the forceps swells up and splits into fine infusible particles, coloring the flame pale green. Gives a blue on ignition with cobalt solution. Soluble in hydrochloric acid, and also in caustic potash.

Obs. — From Barnstaple in Devonshire, England; at Zbirow in Bohemia; at Frankenberg, Saxony; Arbrefontaine, Belgium; Montebras, France; Minas Geraes, Brazil, etc.

In the United States at the slate quarries of York Co., Pa.; White Horse Station, Chester Valley R. R., Pa.; Magnet Cove, Ark.

Fischerite. $AlPO_4.Al(OH)_3.2\frac{1}{2}H_2O$. In small prismatic crystals and in drusy crusts. Color green. Index, 1·55. From Nizhni Tagilsk in the Ural Mts.

Peganite. $Al(PO_4).Al(OH)_3.1\frac{1}{2}H_2O$. Occurs in green crusts, of small prismatic crystals, at Striegis, near Freiberg, Saxony.

TURQUOIS. Turquoise.

Triclinic. Crystals minute and in angle near those of *chalcosiderite* with which it may be isomorphous. Usually massive; amorphous or cryptocrystalline. Reniform, stalactitic, or incrusting. In thin seams and disseminated grains. Also in rolled masses.

Cleavage in two directions in crystals; none in massive material. Fracture small conchoidal. Rather brittle. H. = 5–6. G. = 2·6–2·83. Luster somewhat waxy, feeble. Color sky-blue, bluish green to apple-green, and greenish gray. Streak white or greenish. Feebly subtranslucent to opaque. Optically +. α = 1·61. β = 1·62. γ = 1·65.

Comp. — A hydrous phosphate of aluminium and copper $CuO.3Al_2O_3.2P_2O_5.9H_2O$ or perhaps $H_5(CuOH)[Al(OH)_2]_6(PO_4)_4$ = Phosphorus pentoxide 34·12, alumina 36·84, cupric oxide 9·57, water 19·47 = 100.

Penfield considers that the H,(CuOH) and $Al(OH)_2$ mutually replace each other in the orthophosphoric molecule.

Pyr., etc. — In the closed tube decrepitates, yields water, and turns brown or black. B.B. in the forceps becomes brown and assumes a glassy appearance, but does not fuse; colors the flame green; moistened with hydrochloric acid the color is at first blue (copper chloride). With the fluxes reacts for copper. Soluble in hydrochloric acid.

Obs. — The highly prized oriental turquois occurs in narrow seams (2 to 4 or even 6 mm. in thickness) or in irregular patches in the brecciated portions of a porphyritic trachyte and the surrounding clay slate in Persia, not far from Nishâpûr, Khorassan; in the Megara Valley, Sinai; in the Kara-Tube Mts. in Turkestan, 50 versts from Samarkand.

In the United States, occurs in the Los Cerillos Mts., 20 m. S.E. of Santa Fé, New Mexico, in a trachytic rock, a locality long mined by the Mexicans and in recent years reopened and extensively worked; in the Burro Mts., Grant Co., N. M.; pale green variety near Columbus, and in Lincoln Co., Nevada. In crystals near Lynch Station, Campbell Co., Va.

Natural turquois of inferior color is often artificially treated to give it the tint desired. Moreover, many stones which are of a fine blue when first found retain the color only so long as they are kept moist, and when dry they fade, become a dirty green, and are of little value. Much of the turquois (not artificial) used in jewelry in former centuries, as well as the present, and that described in the early works on minerals, was *bone-turquois* (called also *odontolite*, from ὀδούς, *tooth*), which is fossil bone, or tooth, colored by a phosphate of iron. Its organic origin becomes manifest under a microscope. Moreover, true turquois, when decomposed by hydrochloric acid, gives a fine blue color with ammonia, which is not true of the odontolite.

Use. — As an ornamental material.

Wardite. $2Al_2O_3.P_2O_5.4H_2O$. Forms light green or bluish green concretionary incrustations in cavities of nodular masses of variscite from Cedar Valley, Utah. H. = 5. G. = 2·77.

Sphærite. Perhaps $4AlPO_4.6Al(OH)_3$. In globular drusy concretions. Color light gray, bluish. From near St. Benigna, Bohemia.

Liskeardite. $(Al,Fe)AsO_4.2(Al,Fe)(OH)_3.5H_2O$. In thin incrusting layers, white or bluish. From Liskeard, Cornwall, England.

Evansite. $2AlPO_4.4Al(OH)_3.12H_2O$. Massive; reniform or botryoidal. Colorless, or milk-white. *n* = 1·485. From Zsetcznik, Hungary; Gross-Tresny, Moravia; Tasmania; Coosa coalfield, Ala.; Goldburg, Idaho.

Cœruleolactite. Perhaps $3Al_2O_3.2P_2O_5.10H_2O$. Crypto-crystalline; milk-white to light copper-blue. From near Katzenellnbogen, Nassau, Germany; also East Whiteland Township, Chester Co., Pa.

Augelite. $2Al_2O_3.P_2O_5.3H_2O$. In tabular monoclinic crystals and massive. G. = 2·7. Colorless to white. Optically +. β = 1·576. From Bolivia; from the iron mine of Westanå, Sweden. The same locality has also yielded the three following aluminium phosphates.

Berlinite. $2Al_2O_3.2P_2O_5.H_2O$. Compact, massive. G. = 2·64. Colorless to grayish or rose-red.

Trolleite. $4Al_2O_3.3P_2O_5.3H_2O$. Compact, indistinctly cleavable. G. = 3·10. Color pale green.

Attacolite. $P_2O_5,Al_2O_3,MnO,CaO,H_2O$, etc.; formula doubtful. Massive. G. = 3·09. Color salmon-red.

Minasite. An aluminium phosphate. In rolled pebbles from Brazil.

Vashegyite. $4Al_2O_3.3P_2O_5.30H_2O$. Massive. H. = 2–3. G. = 1·96. Color white or yellow to rust-brown when colored by iron oxide. From iron mine at Vashegy in Comitat Gömör, Hungary.

Soumansite. A fluo-phosphate of aluminium and sodium with water. Tetragonal. Pyramidal habit. H. = 4·5. G. = 2·87. Colorless. Indices, 1·55–1·56. Optically +. Fusible with intumescence. From Montebras in Soumans, Creuse, France.

PHARMACOSIDERITE.

Isometric-tetrahedral. Commonly in cubes; also tetrahedral. Rarely granular.

Cleavage: *a* (100) imperfect. Fracture uneven. Rather sectile. H. = 2·5. G. = 2·9–3. Luster adamantine to greasy, not very distinct. Color olive-, grass- or emerald-green, yellowish brown, honey-yellow. Streak green to brown, yellow, pale. Subtransparent to subtranslucent. *n* = 1·676. Pyroelectric.

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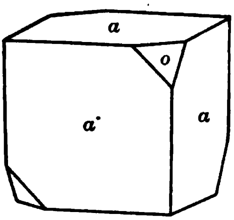


Comp. — Perhaps $6FeAsO_4.2Fe(OH)_3.12H_2O$ = Arsenic pentoxide 43·1, iron sesquioxide 40·0, water 16·9 = 100. Some varieties contain K_2O.

Pyr., etc. — Same as for scorodite.

Obs. — Obtained at the mines in Cornwall, England, with ores of copper; at Schneeberg and Schwarzenberg, Saxony; at Königsberg, near Schemnitz, Hungary. In Utah, at the Mammoth mine, Tintic district. Named from φάρμακον, *poison*, and σίδηρος, *iron*.

Ludlamite. $2Fe_3P_2O_8.Fe(OH)_2.8H_2O$. Occurs in small green tabular crystals (monoclinic), near Truro, Cornwall, England.

Cacoxenite. $FePO_4.Fe(OH)_3.4\frac{1}{2}H_2O$. In radiated tufts of a yellow or brownish color. Indices, 1·58–1·61. From near St. Benigna in Bohemia; Lancaster Co., Pa.

Xanthoxenite. Hydrous ferric phosphate with FeO, MnO, CaO, MgO, Al_2O_3. Monoclinic. In thin plates. Yellow. Pleochroic. G. = 2·84. From Hühnerkobel, Rabenstein, Bavaria.

Beraunite. Perhaps $2FePO_4.Fe(OH)_3.2\frac{1}{2}H_2O$. Commonly in druses and in radiated globules and crusts. Color reddish brown to dark hyacinth-red. From St. Benigna, near Beraun, in Bohemia. From Hellertown, Pa. *Eleonorite,* in tabular crystals, is the same mineral. From the Eleonore mine near Giessen, Germany.

GLOBOSITE, PICITE, DELVAUXITE, KERTSCHENITE, OXYKERTSCHENITE, are other hydrated ferric phosphates.

CHILDRENITE.

Orthorhombic. Axes $a : b : c = 0·7780 : 1 : 0·52575$.

mm''', $110 \wedge 1\bar{1}0$ = 75° 46'. *rr'''*, $131 \wedge 1\bar{3}1$ = 105° 9'.
rr', $131 \wedge \bar{1}31$ = 39° 47'. *ss'*, $121 \wedge \bar{1}21$ = 49° 56½'.

Only known in crystals. Cleavage: *a* (100) imperfect. Fracture uneven. H. = 4·5–5. G. = 3·18–3·24. Luster vitreous to resinous. Color yellowish white, pale yellowish brown, brownish black. Streak white to yellowish. Translucent. 2E = 74°. Optically –. $\alpha = 1·631$. $\beta = 1·660$. $\gamma = 1·664$.

Comp. — In general $2AlPO_4.2Fe(OH)_2.2H_2O$. Phosphorus pentoxide 30·9, alumina 22·2, iron protoxide 31·3, water 15·6 = 100. Manganese replaces part of the iron and it hence graduates into eosphorite.

Pyr., etc. — In the closed tube gives off neutral water. B.B. swells up into ramifications, and fuses on the edges to a black mass, coloring the flame pale green. Heated on charcoal turns black and becomes magnetic. With soda gives a reaction for manganese. With borax and salt of phosphorus reacts for iron and manganese. Soluble in hydrochloric acid.

Obs. — From Tavistock, Devonshire, England; from Greifenstein, Germany. In United States, at Hebron, Me.

KREUZBERGITE. Aluminium phosphate with Fe,Mn,H_2O. Orthorhombic. White to yellow. From the Kreuzberg, Pleystein, Bavaria.

Eosphorite. Form and composition as for childrenite, but containing chiefly manganese instead of iron. In prismatic crystals; also massive. Color rose-pink, yellowish, etc. $\beta = 1·65$. From Branchville, Conn.

Mazapilite. $Ca_3Fe_2(AsO_4)_4.2FeO(OH).5H_2O$. In slender prismatic crystals. G. = 3·567–3·582. Color black. From Mazapil, Mexico.

YUKONITE. $(Ca_3,Fe_2''')(AsO_4)_2.2Fe(OH)_3.5H_2O$. Amorphous. In irregular concretions. H. = 2–3. G. = 2·8. Color nearly black with brown tinge. Decrepitates at low heat, also when immersed in water. Easily fusible with intumescence. From Tagish Lake, Yukon Territory.

Calcioferrite. $Ca_3Fe_2(PO_4)_4.Fe(OH)_3.8H_2O$. Occurs in yellow to green nodules in clay at Battenberg, Rhenish Bavaria, Germany.

Borickite. Perhaps $Ca_3Fe_2(PO_4)_4.12Fe(OH)_3.6H_2O$. Reniform massive; compact. Color reddish brown. From Leoben in Styria; Bohemia. *Fouchérite,* possibly same as borichite from Fouchères, Aube, France.

Egueïite. A hydrous basic phosphate of ferric iron with calcium and aluminium. Amorphous. In small nodules with fibrous-lamellar structure. Index, 1·65. Fusibility 1. Easily soluble in hydrochloric acid. Found embedded in clay from Egueï, Sudan.

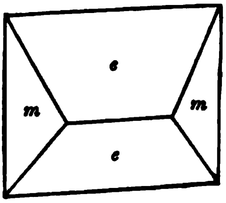
RICHELLITE. Perhaps $4FeP_2O_8.Fe_2OF_2(OH)_2.36H_2O$. Massive, compact or foliated. Color yellow. From Richelle, Belgium.

LIROCONITE.

Monoclinic. Axes $a : b : c = 1·3191 : 1 : 1·6808$; β = 88° 33'.

mm''', $110 \wedge 1\underline{1}0$ = 105° 39'. *me*, $110 \wedge 011$ = 46° 10'.
ee', $011 \wedge 0\bar{1}1$ = 118° 29'. *m'e*, $\bar{1}10 \wedge 011$ = 47° 24'.

990



Crystals resembling rhombic octahedrons. Rarely granular. Cleavage: *m* (110), *e* (011) indistinct. Fracture subconchoidal to uneven. Imperfectly sectile. H. = 2–2·5. G. = 2·882–2·985. Luster vitreous, inclining to resinous. Color and streak sky-blue to verdigris-green.

Comp. — A hydrous arsenate of aluminium and copper, formula uncertain: analyses correspond nearly to $Cu_6Al(AsO_4)_5.3CuAl(OH)_5.20H_2O$ = Arsenic pentoxide 28·9, alumina 10·3, cupric oxide 35·9, water 24·9 = 100. Phosphorus replaces part of the arsenic.

Pyr., etc. — In the closed tube gives much water and turns olive-green. B.B. cracks open, but does not decrepitate; fuses less readily than olivenite to a dark gray slag; on charcoal cracks open, deflagrates, and gives reactions like olivenite. Soluble in nitric acid.

Obs. — From Cornwall; Herrengrund in Hungary.

Chenevixite. Perhaps $Cu_2(FeO)_2As_2O_8.3H_2O$. Massive to compact. Color dark green to greenish yellow. From Cornwall; Utah.

Henwoodite. A hydrated phosphate of aluminium and copper. In botryoidal globular masses. Color turquois-blue. From Cornwall.

Ceruleite. $CuO.2Al_2O_3.As_2O_5.8H_2O$. Compact, made up of very minute crystals. G. = 2·8. Color, turquois-blue. Soluble in acids. From Huanaco, Taltal province, Chile.

Chalcosiderite. $CuO.3Fe_2O_3.2P_2O_5.8H_2O$. Probably isomorphous with turquois and should have $9H_2O$. In sheaf-like crystalline groups, as incrustations. Color light siskin-green. Indices, 1·83–1·93. From Cornwall.

Andrewsite, also from Cornwall, is near chalcosiderite.

Kehoeite. A hydrated phosphate of aluminium, zinc, etc. Massive. G. = 2·34. From Galena, S. D.

Goyazite. Perhaps $Ca_3Al_{10}P_2O_{23}.9H_2O$. Strontia has been found in the mineral and it is possible that it is identical with *hamlinite*. In small rounded grains. Color yellowish white. From Minas Geraes, Brazil.

Roschérite. $(Mn,Fe,Ca)_3Al(OH)(PO_4)_2.2H_2O$. Monoclinic. From Ehrensfriedersdorf, Saxony.

Uranite Group

TORBERNITE. Copper Uranite.

Tetragonal. Axis c = 2·9361. Crystals usually square tables, sometimes very thin, again thick; less often pyramidal. Also foliated, micaceous.

Cleavage: c (001) perfect, micaceous. Laminæ brittle. H. = 2–2·5. G. = 3·4–3·6. Luster of c pearly, other faces subadamantine. Color emerald- and grass-green, and sometimes leek-, apple-, and siskin-green. Streak paler than the color. Transparent to subtranslucent. Optically uniaxial; negative. ω = 1·61.

Comp. — A hydrous phosphate of uranium and copper, $Cu(UO_2)_2P_2O_8.12H_2O$ = Phosphorus pentoxide 14·1, uranium trioxide 56·6, copper 7·9, water 21·4 = 100. Arsenic may replace part of the phosphorus.

Pyr., etc. — In the closed tube yields water. Fuses at 2·5 to a blackish mass, and colors the flame green. With salt of phosphorus gives a green bead, which with tin on charcoal becomes on cooling opaque red (copper). With soda on charcoal gives a globule of copper. Soluble in nitric acid.

Obs. — From Germany at Schneeberg, etc., Saxony; Reichenbach, Baden; at Joachimstal, Bohemia; Ambert, Puy-de-Dôme, France. From Mt. Painter, South Australia. The material from Gunnis Lake, Cornwall corresponds to $Cu(UO_2)_2P_2O_8.8H_2O$ and is the same as the first dehydration product of torbernite, which has been called *meta-torbernite I*. G. = 3·68. ω = 1·623. ϵ = 1·625.

Zeunerite. $Cu(UO_2)_2As_2O_8.8H_2O$. In tabular crystals resembling torbernite in form and color. G. = 3·2. ω = 1·64. From Schneeberg, Saxony; near Joachimstal, Bohemia; Cornwall.

AUTUNITE. Lime Uranite.

Orthorhombic. In thin tabular crystals, nearly tetragonal in form and deviating but slightly from torbernite in angle; also foliated, micaceous.

Cleavage: basal, eminent. Laminæ brittle. H. = 2–2·5. G. = 3·05–3·19. Luster of *c* (001) pearly, elsewhere subadamantine. Color lemon- to sulphur-yellow. Streak yellowish. Transparent to translucent. Optically —. Ax. pl. || *b* (010). Bx ⊥ *c* (001). $\alpha = 1{\cdot}553$. $\beta = 1{\cdot}575$. $\gamma = 1{\cdot}577$.

Comp. — A hydrous phosphate of uranium and calcium, probably analogous to torbernite, $Ca(UO_2)_2P_2O_8.8H_2O$ or $CaO.2UO_3.P_2O_5.8H_2O$ = Phosphorus pentoxide 15·5, uranium trioxide 62·7, lime 6·1, water 15·7 = 100.

Some analyses give 10 and others 12 molecules of water, but it is not certain that the additional amount is essential.

Pyr., etc. — Same as for torbernite, but no reaction for copper.

Obs. — With uraninite, as in Germany at Johanngeorgenstadt and Falkenstein; in Italy at Lurisia, Cuneo; in Madagascar; at Tinh-Tuc, Tongking, China; from Mt. Painter, South Australia. In the United States, at Middletown and Branchville, Conn. In N. C., at mica mines in Mitchell Co.; in Alexander Co.; Black Hills, S. D.

Bassetite. Composition probably the same as *autunite*. Monoclinic. $\beta = 89° 17'$. Twinned; tw. pl. *b* (010). Cleavage parallel to three pinacoids. G. = 3·10. Color yellow. Transparent. Indices, 1·57–1·58. From the Basset mines, Cornwall. Previously considered to be *autunite*.

Uranospinite. Probably $Ca(UO_2)_2As_2O_8.8H_2O$. In thin tabular orthorhombic crystals rectangular in outline. Color siskin-green. $\beta = 1{\cdot}63$. From near Schneeberg, Saxony.

Uranocircite. $Ba(UO_2)_2P_2O_8.8H_2O$. In crystals similar to autunite. Color yellow-green. $\beta = 1{\cdot}62$. From Falkenstein, Saxon Voigtland, Germany.

Carnotite. Approximately, $K_2O.2U_2O_3.V_2O_5.3H_2O$. Orthorhombic. In the form of powder, sometimes in crystalline plates || *c* (001). Basal cleavage. Color yellow. $\beta = 1{\cdot}86$. Occurs as a yellow crystalline powder, or in loosely cohering masses, intimately mixed with quartzose material. It is found in large quantities in western Colorado and eastern Utah. Is mined there not only for its uranium and vanadium content but also for the small amount of radium it contains. Noted also from Radium Hill, near Olary, South Australia, and from near Mauch Chunk, Pa.

TYUYAMUNITE. $CaO.2UO_3.V_2O_5.4H_2O$. Perhaps a calcium carnotite. Found at Tyuya-Muyun, Fergana, Russian Central Asia.

Uranospathite. A hydrated uranyl phosphate. Orthorhombic, pseudo-tetragonal. In elongated tabular crystals. Cleavages parallel to the three pinacoids. Color yellow to pale green. From Redruth, Cornwall. Previously considered to be *autunite*.

Phosphuranylite. $(UO_2)_3P_2O_8.6H_2O$. As a pulverulent incrustation. Color deep lemon-yellow. From Mitchell Co., N. C.

Trögerite. $(UO_2)_3As_2O_8.12H_2O$. In thin druses of tabular crystals. Probably tetragonal. Color lemon-yellow. From near Schneeberg, Saxony.

Walpurgite. Probably $Bi_{10}(UO_2)_3(OH)_{24}(AsO_4)_4$. In thin yellow crystals resembling gypsum. G. = 5·76. Color yellow. Index, 2·00. From near Schneeberg, Saxony.

Rhagite. Perhaps $2BiAsO_4.3Bi(OH)_3$. In crystalline aggregates. Color yellowish green, wax-yellow. From near Schneeberg, Saxony.

ARSENO-BISMITE. A hydrous bismuth arsenate. In cryptocrystalline aggregates. Color yellowish green with tinge of brown. G. = 5·7. Index, 1·6. Found at Mammoth mine, Tintic district, Utah.

Mixite. A hydrated basic arsenate of copper and bismuth, formula doubtful. In acicular crystals; as an incrustation. Color green to whitish. From Joachimstal, Bohemia; Wittichen, Baden; Tintic district, Utah.

Antimonates; also Antimonites, Arsenites.

A number of antimonates have been included in the preceding pages among the phosphates, arsenates, etc.

Bindheimite. A hydrous antimonate of lead. Amorphous, reniform; also earthy or incrusting. Color gray, brownish, yellowish. Index, 2·0. A result of the decomposition

Comp. — $HRBO_3$, where R = Mn, Zn and Mg = Boron trioxide 34·1, manganese protoxide, 41·5, magnesia 15·6, water 8·8 = 100. Here Mn (+ Zn) : Mg = 3 : 2.

Pyr., etc. — In the closed tube darkens in color and yields neutral water. If turmeric paper is moistened with this water, and then with dilute hydrochloric acid, it assumes a red color (boric acid). In the forceps fuses in the flame of a candle (F. = 2), and B.B. in O.F. yields a black crystalline mass, coloring the flame intensely yellowish green. With the fluxes reacts for manganese. Soluble in hydrochloric acid.

Obs. — Found on Mine Hill, Franklin Furnace, Sussex Co., N. J., with franklinite, zincite, willemite, etc. An intimate mixture of zincite and calcite, not uncommon at Mine Hill, is often mistaken for sussexite, but the ready fusibility of the genuine mineral is distinctive.

Ludwigite. Perhaps $3MgO.B_2O_3.FeO.Fe_2O_3$. Orthorhombic. In finely fibrous masses. G. = 3·91–4·02. Color blackish green to nearly black. Index, 1·86. Strongly pleochroic. From Morawitza, Hungary. *Collbranite* from Korea is ludwigite.

VONSENITE. $3(Fe,Mg)O.B_2O_3.FeO.Fe_2O_3$. Similar to ludwigite with more ferrous iron. Riverside, Cal.

Magnesioludwigite. $3MgO.B_2O_3.MgO.Fe_2O_3$. From Mountain Lake mine, south of Brighton, Utah.

Pinakiolite. $3MgO.B_2O_3.MnO.Mn_2O_3$. In small rectangular crystals. H. = 6. G. = 3·881. Luster metallic. Color black. From Långban, Sweden.

Nordenskiöldine. A calcium-tin borate, $CaSn(BO_3)_2$. In tabular rhombohedral crystals. H. = 5·5–6. G. = 4·20. Color sulphur-yellow. From the Langesund fiord, Norway.

Jeremejevite. Eichwaldite. Aluminium borate, $AlBO_3$. In prismatic hexagonal crystals. H. = 6·5. G. = 3·28. Colorless to pale yellow. Index, 1·64. From Mt. Soktuj, Adun-Chalon range in Eastern Siberia.

Hambergite. $Be_2(OH)BO_3$. In grayish white orthorhombic prismatic crystals. H. = 7·5. G. = 2·347. Optically +. $\beta = 1·588$. From Langesund fiord, southern Norway; various localities in Madagascar.

Szaibelyite. $2Mg_5B_4O_{11}.3H_2O$. In small nodules; white outside, yellow within. From Rezbánya, Hungary.

BORACITE.

Isometric and tetrahedral in external form under ordinary conditions, but in molecular structure orthorhombic and pseudo-isometric; the structure becomes isotropic, as required by the form, only when heated to 265°. (See Art. **429**.)

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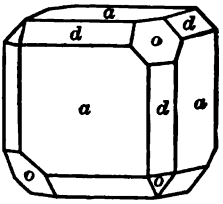

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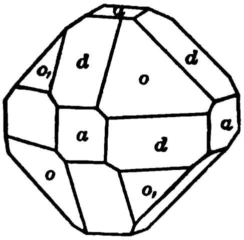

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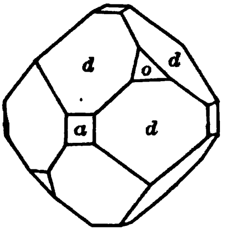

Habit cubic and tetrahedral or octahedral; also dodecahedral. Crystals usually isolated, embedded; less often in groups. Faces *o* (111) bright and smooth, *o,* ($\bar{1}11$) dull or uneven.

Cleavage: *o*, *o,* in traces. Fracture conchoidal, uneven. Brittle. H. = 7 in crystals. G. = 2·9–3. Luster vitreous, inclining to adamantine. Color white, inclining to gray, yellow and green. Streak white. Subtransparent to translucent. Commonly shows double refraction, which, however, disappears upon heating to 265°, when a section becomes isotropic. Refractive index, $n = 1{\cdot}667$; $\gamma - \alpha = 0{\cdot}0107$.

Strongly pyroelectric, the opposite polarity corresponding to the position of the + and − tetrahedral faces (see pp. 306, 307). The faces of the dull tetrahedron $o_{\prime}$ $(1\bar{1}1)$ form the analogous pole, those of the polished form *o* (111) the antilogous pole.

Comp. — $Mg_7Cl_2B_{16}O_{30}$ or $6MgO.MgCl_2.8B_2O_3$ = Boron trioxide 62·5, magnesia 31·4, chlorine 7·9 = 101·8, deduct (O = Cl) 1·8 = 100.

Var. — 1. *Ordinary.* In crystals of varied habit. 2. *Massive*, with sometimes a subcolumnar structure; *stassfurtite* of Rose. It resembles a fine-grained white marble or granular limestone. *Parasite* of Volger is the plumose interior of some crystals of boracite. 3. *Eisenstassfurtite* contains some Fe.

Pyr., etc. — The massive variety gives water in the closed tube. B.B. both varieties fuse at 2 with intumescence to a white crystalline pearl, coloring the flame green; heated after moistening with cobalt solution assumes a deep pink color. Mixed with oxide of copper and heated on charcoal colors the flame deep azure-blue (copper chloride). Soluble in hydrochloric acid.

Alters very slowly on exposure, owing to the magnesium chloride present, which takes up water. It is the frequent presence of this deliquescent chloride in the massive mineral, thus originating, that led to the view that there was a hydrous boracite (stassfurtite). *Parasite* of Volger is a result of the same kind of alteration in the interior of crystals of boracite; this alteration giving it its somewhat plumose character, and introducing water.

Obs. — Observed in beds of anhydrite, gypsum or salt. In crystals in Germany at Kalkberg and Schildstein in Lüneburg, Hannover; at Segeberg, near Kiel, in Holstein; massive, or as part of the rock, also in crystals, at Stassfurt, Prussia; at Luneville, La Meurthe, France.

Ascharite. A hydrous magnesium borate. In white lumps with boracite. G. = 2·7. Index, 1·54. From Aschersleben and Neustassfurt, Germany. *Paternoite.* A similar mineral from Sicily.

Rhodizite. A borate of aluminium and potassium, with cæsium and rubidium. Isometric-tetrahedral; in white, translucent dodecahedrons. H. = 8. G. = 3·41. $n = 1{\cdot}69$. Found on red tourmaline from near Ekaterinburg, Ural Mts.; from Madagascar.

Warwickite. $(Mg, Fe)_3TiB_2O_8$. In elongated prismatic crystals. G. = 3·36. Color dark brown to dull black. From Edenville, N. Y.

Howlite. A silico-borate of calcium, $H_5Ca_2B_5SiO_{14}$. In small white rounded nodules; also earthy. From Nova Scotia; Lang, Los Angeles Co., and in San Bernardino Co., Cal.

Lagonite. $Fe_2O_3.3B_2O_3.3H_2O$. An incrustation at the Tuscan lagoons, Italy.

Larderellite. $(NH_4)_2B_{10}O_{16}.5H_2O$. From the Tuscan lagoons, Italy.

COLEMANITE.

Monoclinic. Axes $a : b : c = 0{\cdot}7748 : 1 : 0{\cdot}5410$; $\beta = 69° 51'$.

Crystals usually short prismatic (mm''' $110 \wedge 1\bar{1}0 = 72° 4'$). Massive cleavable to granular and compact.

Cleavable: *b* (010) highly perfect; *c* (001) distinct. Fracture uneven to subconchoidal. H. = 4–4·5. G. = 2·42. Luster vitreous to adamantine, brilliant. Colorless to milky white, yellowish white, gray. Transparent to translucent. Optically +. $\alpha = 1{\cdot}586$. $\beta = 1{\cdot}592$. $\gamma = 1{\cdot}614$.

Comp. — $Ca_2B_6O_{11}.5H_2O$, perhaps $HCa(BO_2)_3.2H_2O$ = Boron trioxide 50·9, lime 27·2, water 21·9 = 100.

Pyr. — B.B. decrepitates, exfoliates, sinters, and fuses imperfectly, coloring the flame yellowish green. Soluble in hot hydrochloric acid with separation of boric acid on cooling.

Obs. — First discovered in Death Valley, Inyo Co., Cal.; later in Calico district, San Bernardino Co. *Neocolemanite* from Lang, Los Angeles Co., Cal., is identical with colemanite.

Priceite. Near colemanite. Massive, friable and chalky. Color snow-white. From Curry Co., Oregon. *Pandermite* is similar; in compact nodules from Asia Minor; Argentina.

Inyoite. $2CaO.3B_2O_3.13H_2O$. Monoclinic. In large tabular crystals. Cleavage, *c* (001). H. = 2. G. = 1·87. Indices, 1·49–1·52. Decrepitates and fuses with intumescence, giving green flame. Largely altered into *meyerhofferite*. From Mt. Blanco district, on Furnace Creek, near Death Valley, Inyo Co., Cal. Associated with *colemanite*.

Meyerhofferite. $2CaO.3B_2O_3.7H_2O$. Triclinic crystals prismatic, often tabular parallel to *a* (100). Fibrous. Cleavage, *b* (010). H. = 2. G. = 2·12. Colorless to white. Indices, 1·50–1·56. Fuses without decrepitation but with intumescence. Found with *inyoite* (which see) as an alteration product.

Pinnoite. $MgB_2O_4.3H_2O$. Tetragonal-pyramidal. Usually in nodules, radiated fibrous. G. = 2·29. Color sulphur- or straw-yellow. ω = 1·56. From Stassfurt, Germany.

Heintzite. Hintzeite. Kaliborite. A hydrous borate of magnesium and potassium. In small monoclinic crystals, sometimes aggregated together. H. = 4–5. G. = 2·13. Colorless to white. β = 1·525. From Leopoldshall, Stassfurt, Germany.

Hulsite. $12(Fe,Mg)O.2Fe_2O_3.1SnO_2.3B_2O_3.2H_2O$. Orthorhombic (?) as small crystals or tabular masses. H. = 3. G. = 4·3. Color and streak black. Fusible. Found in metamorphosed limestone at a granite contact at Brooks mountain, Seward Peninsula, Alaska. *Paigeite* is a similar mineral from the same locality with the composition, $30FeO.5Fe_2O_3.1SnO_2.6B_2O_3.5H_2O$.

BORAX.

Monoclinic. Axes $a : b : c = 1·0995 : 1 : 0·5632$; $\beta = 73° 25'$.

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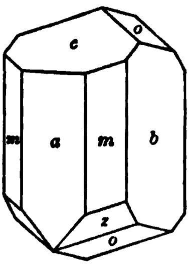


ca,	$001 \wedge \bar{1}00 = 73° 25'$.	*cz*,	$001 \wedge \bar{2}21 = 64° \ 8'$.
mm''',	$110 \wedge 1\bar{1}0 = 93° \ 0'$.	*oo'*,	$\bar{1}11 \wedge \bar{1}\bar{1}1 = 57° 27'$.
co,	$001 \wedge \bar{1}11 = 40° 31'$.	*zz'*,	$\bar{2}21 \wedge \bar{2}\bar{2}1 = 83° 28'$.

Crystals prismatic, sometimes large; resembling pyroxene in habit and angles.

Cleavage: *a* (100) perfect; *m* (110) less so; *b*(010) in traces. Fracture conchoidal. Rather brittle. H. = 2–2·5. G. = 1·69–1·72. Luster vitreous to resinous; sometimes earthy. Color white; sometimes grayish, bluish or greenish. Streak white. Translucent to opaque. Taste sweetish alkaline, feeble. Optically –. Ax. pl. ⊥ *b* (010). $Bx_a \perp b$ (010). $Bx_{o.r} \wedge c$ axis = – 56° 50'. 2V = 39°. α = 1·447. β = 1·470. γ = 1·472.

Comp. — $Na_2B_4O_7.10H_2O$ or $Na_2O.2B_2O_3.10H_2O$ = Boron trioxide 36·6, soda 16·2, water 47·2 = 100.

Pyr., etc. — B.B. puffs up and afterward fuses to a transparent globule, called the glass of borax. Fused with fluorite and potassium bisulphate, it colors the flame around the assay a clear green. Soluble in water, yielding a faintly alkaline solution. Boiling water dissolves double its weight of this salt.

Obs. — Obtained from the salt lakes of Tibet; the crude mineral is called *tincal*. In Cal., abundant in Lake Co., at Borax Lake and Hachinhama, two small alkaline lakes in the immediate vicinity of Clear Lake; present in solution in the lake waters, and obtained also in large quantities in fine crystals embedded in the lake mud and the surrounding marshy soil; also found in fine large clear crystals at Borax Lake, San Bernardino Co.; at Death Valley, Inyo Co. Also Rhodes Marsh, etc., Esmeralda Co., Nev.

Named borax from the Arabic *buraq*, which included also the *niter* (sodium carbonate) of ancient writers, the *natron* of the Egyptians. Borax was called chrysocolla by Agricola because used in soldering gold.

Use. — Borax is used for washing and cleansing; as an antiseptic and preservative; as a solvent for metallic oxides in soldering and welding; as a flux.

ULEXITE. Boronatrocalcite. Natronborocalcite.

Usually in rounded masses, loose in texture, consisting of fine fibers, which are acicular or capillary crystals. H. = 1. G. = 1·65. Luster silky within. Color white. Tasteless. Optically +. α = 1·500. β = 1·508. γ = 1·520.

Comp. — A hydrous borate of sodium and calcium, probably $NaCaB_5O_9.8H_2O$ = Boron trioxide 43·0, lime 13·8, soda 7·7, water 35·5 = 100.

Pyr., etc. — Yields water. B.B. fuses at 1 with intumescence to a clear blebby glass, coloring the flame deep yellow. Moistened with sulphuric acid the color of the flame is momentarily changed to deep green. Not soluble in cold water, and but little so in hot; the solution alkaline in its reactions.

Obs. — From the dry plains of Iquique, Chile. In Nev., in large quantities in the salt marshes of the Columbus Mining District, Esmeralda Co.

Named after the German chemist, G. L. Ulex.

Bechilite. $CaB_4O_7.4H_2O$. In crusts, as a deposit from springs in Tuscany, Italy.

Hydroboracite. $CaMgB_6O_{11}.6H_2O$. Resembles fibrous and foliated gypsum; color white. $\beta = 1·587$. From the Caucasus Mts.

Sulphoborite. $2MgSO_4.4MgHBO_3.7H_2O$. In colorless prismatic orthorhombic crystals. H. = 4. G. = 2·38–2·45. Optically −. $\beta = 1·540$. From Westeregeln, and Wittmar, Germany.

Uranates

URANINITE. Cleveite. Bröggerite. Nivenite. Pitchblende.

Isometric. In octahedrons (*o*), also with dodecahedral faces (*d*); less often in cubes with *o* and *d*. Crystals rare. Usually massive and botryoidal; also in grains; structure sometimes columnar, or curved lamellar.

Fracture conchoidal to uneven. Brittle. H. = 5·5. G. = 9·0 to 9·7 of crystals; of massive altered forms from 6·4 upwards. Luster submetallic, to greasy or pitch-like, and dull. Color grayish, greenish, brownish, velvet-black. Streak brownish black, grayish, olive-green, a little shining. Opaque.

Comp. — A uranate of uranyl, lead, usually thorium (or zirconium), often the metals of the lanthanum and yttrium groups; also containing the gases nitrogen, helium and argon, in varying amounts up to 2·6 p. c. Calcium and water (essential?) are present in small quantities; iron also, but only as an impurity. The relation between the bases varies widely and no definite formula can be given. Radium was first discovered in this mineral and it has been shown that it and the helium present are products of the breaking down of the uranium.

Var. — The minerals provisionally included under the name uraninite are as follows:

1. *Crystallized.* *Uranniobite* from Norway. In crystals, usually octahedral, with G. varying for the most part from 9·0 to 9·7; occurs as an original constituent of coarse granites. The variety from Branchville, Conn., which is as free from alteration as any yet examined, contains chiefly UO_2 with a relatively small amount of UO_3. Thoria is prominent, while the earths of the lanthanum and yttrium groups are only sparingly represented.

Bröggerite, as analyzed by Hillebrand, gives the oxygen ratio of UO_3 to other bases of about 1 : 1; it occurs in octahedral crystals, also with *d* (110) and *a* (100). G. = 9·03.

Cleveite and *nivenite* contain UO_3 in larger amount than the other varieties mentioned, and are characterized by containing about 10 p. c. of the yttrium earths. Cleveite is a variety from the Arendal, Norway, region occurring in cubic crystals modified by the dodecahedron and octahedron. G. = 7·49. It is particularly rich in the gas helium. Nivenite occurs massive, with indistinct crystallization. Color velvet-black. H. = 5·5. G. = 8·01. It is more soluble than other kinds of uraninite, being completely decomposed by the action for one hour of very dilute sulphuric acid at 100°.

2. *Massive*, probably amorphous. Pitchblende. Contains no thoria; the rare earths also absent. Water is prominent and the specific gravity is much lower, in some cases not above 6·5; these last differences are doubtless largely due to alteration. Here belong the kinds of pitchblende which occur in metalliferous veins, with sulphides of silver, lead, cobalt, nickel, iron, zinc, copper, as that from Johanngeorgenstadt, Germany; Přibram, Bohemia, etc.; probably also that from Black Hawk, Col.

Pyr., etc. — B.B. infusible, or only slightly rounded on the edges, sometimes coloring the outer flame green (copper). With borax and salt of phosphorus gives a yellow bead in O.F., becoming green in R.F. (uranium). With soda on charcoal gives a coating of lead oxide, and frequently the odor of arsenic. Many specimens give reactions for sulphur and arsenic in the open tube. Soluble in nitric and sulphuric acids; the solubility differs widely in different varieties, being greater in those kinds containing the rare earths. Not attractable by the magnet. Strongly radioactive.

Obs. — As noted above, uraninite occurs either as a primary constituent of granitic rocks or as a secondary mineral with ores of silver, lead, copper, etc. Under the latter conditions it is found in Germany at Johanngeorgenstadt, Marienberg, and Schneeberg in Saxony; in Bohemia at Joachimstal and Přibram; in Hungary at Rezbánya. Occurs in Norway in pegmatitic veins at several points near Moss, viz.: Anneröd (*bröggerite*), Elvestad, etc.; also near Arendal at the Garta feldspar quarry (*cleveite*), associated with orthite, fergusonite, thorite, etc.

In the United States, at the Middletown feldspar quarry, Conn., in large octahedrons, rare; at Hale's quarry in Glastonbury, a few miles N.E. of Middletown. At Branchville, Conn., in a pegmatite vein, as small octahedral crystals, embedded in albite. In N. C., at the Flat Rock mine and other mica mines in Mitchell Co., rather abundant, but usually altered, in part or entirely, to gummite and uranophane; the crystals are sometimes an inch or more across and cubic in habit. In S. C., at Marietta. In Texas, at the gadolinite locality in Llano Co. (*nivenite*). In large quantities at Black Hawk, near Central City, Col. Rather abundant in the Bald Mountain district, Black Hills, S. D. Also with monazite, etc., at the Villeneuve mica veins, Ottawa Co., Quebec, Canada.

Use. — As a source of uranium and of radium salts.

Gummite. An alteration-product of uraninite of doubtful composition. In rounded or flattened pieces, looking much like gum. G. = 3·9–4·20. Luster greasy. Color reddish yellow to orange-red, reddish brown. $n = 1·61$. From Johanngeorgenstadt, Germany, also Mitchell Co., N. C.

YTTROGUMMITE. Occurs with cleveite as a decomposition-product.

THOROGUMMITE. Occurs with fergusonite, cyrtolite, and other species at the gadolinite locality in Llano Co., Texas.

Thorianite. Chiefly thorium and uranium oxides. Isometric, cubic habit. G. = 9·3. Color black. Radioactive. Obtained from gem gravels of Balangoda, Ceylon. Also noted from Province of Betroka, Madagascar.

Uranosphærite. $(BiO)_2U_2O_7.3H_2O$. In half-globular aggregated forms. Color orange-yellow, brick-red. From near Schneeberg, Saxony.

Oxygen Salts

6. SULPHATES, CHROMATES, TELLURATES

A. Anhydrous Sulphates, etc.

The important BARITE GROUP is the only one among the anhydrous sulphates and chromates.

Mascagnite. Ammonium sulphate, $(NH_4)_2SO_4$. Orthorhombic. Usually in crusts and stalactitic forms. $\beta = 1·523$. Occurs about volcanoes, as at Etna, Vesuvius, etc.

Taylorite. $5K_2SO_4.(NH_4)_2SO_4$. In small compact lumps or concretions. From the guano of the Chincha Islands.

Thenardite. Anhydrous sodium sulphate, Na_2SO_4. In orthorhombic crystals, pyramidal, short prismatic or tabular; also as twins (Fig. 384, p. 160). White to brownish. Optically +. $\beta = 1·477$. Soluble in water. Often observed in connection with salt lakes, as on the shores of Lake Balkhash, Central Asia; similarly elsewhere; also in South America in Tarapaca, Chile. In the United States, forms extensive deposits on the Rio Verde, Ariz. In Cal., at Borax Lake, San Bernardino Co.

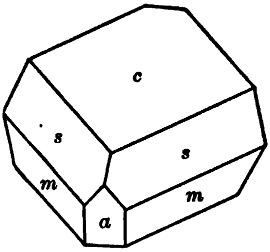
Aphthitalite. Arcanite. Glaserite. $(K,Na)_2SO_4$. Rhombohedral; also massive, in crusts. Color white. From Vesuvius, upon lava; at Douglashall near Westeregeln, Germany, in blödite; Stassfurt, Germany; Rocalmuto, Sicily.

GLAUBERITE.

Monoclinic. Axes $a : b \cdot c = 1{\cdot}2200 : 1 : 1{\cdot}0275$; $\beta = 67° 49'$.

ca, 001 ∧ 100 = 67° 49′. cs, 001 ∧ 111 = 43° 2′.
mm''', 110 ∧ $1\bar{1}0$ = 96° 58′. cm, 001 ∧ 110 = 75° 30½′.

995



In crystals tabular || c (001); also prismatic.

Cleavage: c perfect. Fracture conchoidal. Brittle. H. = 2·5–3. G. = 2·7–2·85. Luster vitreous. Color pale yellow or gray; sometimes brick-red. Streak white. Taste slightly saline. Optically –. 2V = 7°. $\alpha = 1{\cdot}515$. $\beta = 1{\cdot}532$. $\gamma = 1{\cdot}536$. Optical characters change on heating, see p. 297.

Comp. — $Na_2SO_4.CaSO_4$ = Sulphur trioxide 57·6, lime 20·1, soda 22·3 = 100; or, Sodium sulphate 51·1, calcium sulphate 48·9 = 100.

Pyr., etc. — B.B. decrepitates, turns white, and fuses at 1·5 to a white enamel, coloring the flame intensely yellow. On charcoal fuses in O.F. to a clear bead; in R.F. a portion is absorbed by the charcoal, leaving an infusible hepatic residue. Soluble in hydrochloric acid. In water it loses its transparency, is partially dissolved, leaving a residue of calcium sulphate, and in a large excess this is completely dissolved.

Obs. — In crystals in rock salt at Villa Rubia, in New Castile, Spain; also at Aussee and Hallstatt, Upper Austria; in Germany at Berchtesgaden, Bavaria; Westeregeln; Stassfurt. In crystals in the Rio Verde Valley, Ariz., with thenardite, mirabilite, etc.; Borax lake, San Bernardino Co., Cal.

Langbeinite. $K_2Mg_2(SO_4)_3$. Isometric-tetartohedral. In highly modified colorless crystals. G. = 2·83. $n = 1{\cdot}533$. From Westeregeln and Stassfurt, Germany; Hall, Tyrol; Punjab, India.

Vanthoffite. $3Na_2SO_4.MgSO_4$. Almost colorless crystalline material found at Wilhelmshall, near Stassfurt, Prussia.

Barite Group. RSO_4. Orthorhombic

		$m \wedge m'''$	dd'	oo'	
		$110 \wedge 1\bar{1}0$	$102 \wedge \bar{1}02$	$011 \wedge 0\bar{1}1$	$a : b : c$
Barite	$BaSO_4$	78° 22½′	77° 43′	105° 26′	0·8152 : 1 : 1·3136
Celestite	$SrSO_4$	75° 50′	78° 49′	104° 0′	0·7790 : 1 : 1·2801
Anglesite	$PbSO_4$	76° 16½′	78° 47′	104° 24½′	0·7852 : 1 : 1·2894
Anhydrite	$CaSO_4$	(83° 33′)	(58° 31′)	(90° 3′)	0·8933 : 1 : 1·0008

The BARITE GROUP includes the sulphates of barium, strontium, and lead, three species which are closely isomorphous, agreeing not only in axial ratio but also in crystalline habit and cleavage. With these is also included calcium sulphate, anhydrite, which has a related but not closely similar form; it differs from the others conspicuously in cleavage. It is to be noted that the carbonates of the same metals form the isomorphous ARAGONITE GROUP, p. 437.

BARITE. Heavy Spar. Barytes.

Orthorhombic. Axes $a : b : c = 0{\cdot}8152 : 1 : 1{\cdot}3136$.

mm''', 110 ∧ $1\bar{1}0$ = 78° 22½′. dd''', 102 ∧ $10\bar{2}$ = 102° 17′.
cd, 001 ∧ 102 = 38° 51½′. oo''', 011 ∧ $01\bar{1}$ = 74° 34′.
co, 001 ∧ 011 = 52° 43′. cz, 001 ∧ 111 = 64° 19′.

Crystals commonly tabular || c (001), and united in diverging groups having the axis b in common; also prismatic, most frequently || axis b, d (102) predominating; also || axis c, m (110) prominent; again || axis a, with o (011) prominent. Also in globular forms, fibrous or lamellar, crested; coarsely laminated, laminæ convergent and often curved; granular, resembling white marble, and earthy; colors sometimes banded as in stalagmite.

Cleavage: *c* (001) perfect; *m* (110) also perfect, Fig. 996 the form yielded

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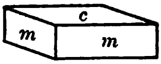

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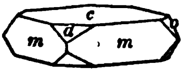

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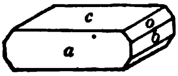

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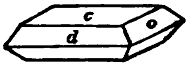

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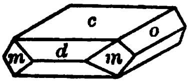

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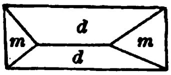

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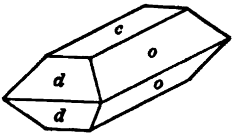

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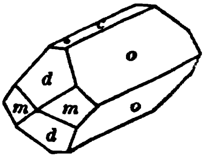

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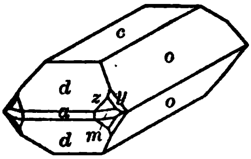


by cleavage; also *b* (010) imperfect. Fracture uneven. Brittle. H. = 2·5–3·5. G. = 4·3–4·6. Luster vitreous, inclining to resinous; sometimes pearly on *c* (001), less often on *m* (110). Streak white. Color white; also inclining to yellow, gray, blue, red, or brown, dark brown. Transparent to translucent to opaque. Sometimes fetid, when rubbed. Optically +. Ax. pl. || *b* (010). Bx ⊥ *a* (100). 2V = 37° 30′. $\alpha = 1.636$. $\beta = 1·637$. $\gamma = 1·648$.

Var. — *Ordinary.* (*a*) Crystals usually broad or stout; sometimes very large; again in slender needles. (*b*) *Crested;* massive aggregations of tabular crystals, the crystals projecting at surface into crest-like forms. (*c*) *Columnar;* the columns often coarse and loosely aggregated, and either radiated or parallel; rarely fine fibrous. (*d*) In globular or nodular concretions, subfibrous or columnar within. *Bologna Stone* (from near Bologna) is here included; it was early a source of wonder because of the phosphorescence it exhibited after heating with charcoal. "Bologna phosphorus" was made from it. (*e*) Lamellar, either straight or curved; the latter sometimes as aggregations of curved scale-like plates. (*f*) Granular. (*g*) Compact or cryptocrystalline. (*h*) Earthy. (*i*) Stalactitic and stalagmitic; similar in structure and origin to calcareous stalactites and stalagmites and of much beauty when polished. (*h*) *Fetid;* so called from the odor given off when struck or when two pieces are rubbed together, which odor may be due to carbonaceous matters present.

The barite of Muzsaj and of Betler, near Rosenau, Hungary, was early called *Wolnyn*. *Cawk* is the ordinary barite of the Derbyshire lead mines. *Dreelite*, supposed to be rhombohedral, is simply barite. *Michel-lévyte* from Perkin's Mill, Templeton, Quebec (described as monoclinic), is peculiar in its pearly luster on *m*, twinning striations, etc.

Comp. — Barium sulphate, $BaSO_4$ = Sulphur trioxide 34·3, baryta 65·7 = 100.

Strontium sulphate is often present, also calcium sulphate; further, as impurities, silica, clay, bituminous or carbonaceous substances.

Pyr, etc. — B.B. decrepitates and fuses at 3, coloring the flame yellowish green; the fused mass reacts alkaline with test paper. On charcoal reduced to a sulphide. With soda gives at first a clear pearl, but on continued blowing yields a hepatic mass, which spreads out and soaks into the coal. This reacts for sulphur (p. 340). Insoluble in acids.

Diff. — Characterized by high specific gravity (higher than celestite, aragonite, albite, calcite, gypsum, etc.); cleavage; insolubility; *green* coloration of the blowpipe flame. Albite is harder and calcite effervesces with acid.

Obs. — Occurs commonly in connection with beds or veins of metallic ores, especially of lead, also copper, silver, cobalt, manganese, as part of the gangue of the ore; also often accompanies stibnite. Sometimes present in massive forms with hematite deposits. It is met with in secondary limestones and sandstones, sometimes forming distinct veins, and in the former often in crystals along with calcite and celestite; in the latter often with copper ores. Sometimes occupies the cavities of amygdaloidal basalt, porphyry, etc.; forms earthy masses in beds of marl. Occurs as the petrifying material of fossils and occupying cavities in them.

Fine crystals are obtained in England at the Dufton lead mines, Westmoreland; also in Cumberland and Lancashire; in Derbyshire, Staffordshire, etc.; Cleator Moor; Alston Moor. In Scotland, in Argyleshire, at Strontian. Some of the most important of the many European localities are Felsöbánya, Nagybánya. Schemnitz, and Kremnitz, in Hungary, and Ilefeld, often with stibnite; Hüttenberg, Carinthia; Freiberg, Marienberg, in Saxony; Claustal in the Harz Mts.; Přibram, Bohemia; Auvergne, France.

In the United States, formerly in Conn., at Cheshire intersecting the red sandstone in veins with chalcocite and malachite. In N. Y., at Pillar Point, opposite Sackett's Harbor, massive; at Scoharie, fibrous; in St. Lawrence Co., crystals at De Kalb; the crested variety at Hammond. In Pa., in crystals at Perkiomen lead mine. In Va., at Eldridge's gold mine in Buckingham Co. In N. C., white massive at Crowders Mt., Gaston Co., etc. In Tenn., on Brown's Creek; at Haysboro', near Nashville; in large veins in sandstone on the west end of Isle Royale, Lake Superior, and on Spar Island, north shore. In Mo. not uncommon with the lead ores; in concretionary forms at Salina, Saline Co., Kan. In Col., at Sterling, Weld Co.; Apishapa Creek; also in El Paso and Fremont Cos. In fine crystals, near Fort Wallace, N. M. Crystals enclosing quartz sand, "sand barite," from Norman, Oklahoma. In distorted crystals from the Bad Islands, S. D.

In Ontario, in Bathurst, and North Burgess, Lanark Co.; Malway, Peterborough Co.; as large veins on Jarvis, McKellars, and Pie islands, in Lake Superior, and near Fort William, Thunder Bay. In Nova Scotia, in veins in the slates of East River of the Five Islands, Colchester Co.

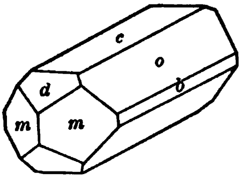
Named from *βαρυς, heavy*.

Use. — Source of barium hydroxide used in the refining of sugar; ground and used as a pigment, to give weight to paper, cloth, etc.

CELESTITE. Cœlestine.

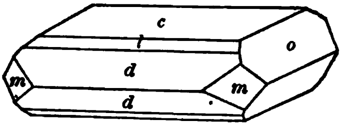
Orthorhombic. Axes $a : b : c = 0{\cdot}7790 : 1 : 1{\cdot}2800$.

1005



mm‴, 110 ∧ 1$\bar{1}$0 = 75° 50′.
cl, 001 ∧ 104 = 22° 20′.

1006



cd, 001 ∧ 102 = 39° 24½′.
co, 001 ∧ 011 = 52° 0′.

Crystals resembling those of barite in habit; commonly tabular || *c* (001) or prismatic || axis *a* or *b*; also more rarely pyramidal by the prominence of the forms *ψ* (133) or *χ* (144). Also fibrous and radiated; sometimes globular; occasionally granular.

Cleavage: *c* (001) perfect; *m* (110) nearly perfect; *b* (010) less distinct. Fracture uneven. H. = 3–3·5. G. = 3·95–3·97. Luster vitreous, sometimes inclining to pearly. Streak white. Color white, often faint bluish, and sometimes reddish. Transparent to subtranslucent. Optically +. Ax. pl. || *b* (010). Bx ⊥ *a* (100). 2V = 51°. $\alpha = 1{\cdot}622$. $\beta = 1{\cdot}624$. $\gamma = 1{\cdot}631$.

Var. — 1. *Ordinary.* (*a*) In crystals of varied habit as noted above; a tinge of a delicate blue is very common and sometimes belongs to only a part of a crystal. The variety from Montmartre, near Paris, France, called *apotome*, is prismatic by extension of *o* (011) and doubly terminated by the pyramid *ψ* (133). (*b*) Fibrous, either parallel or radiated. (*c*) Lamellar; of rare occurrence. (*d*) Granular. (*e*) Concretionary. (*f*) Earthy; impure usually with carbonate of lime or clay.

Comp. — Strontium sulphate, $SrSO_4$ = Sulphur trioxide 43·6, strontia 56·4 = 100. Calcium and barium are sometimes present.

Pyr., etc. — B.B. frequently decrepitates, fuses at 3 to a white pearl, coloring the flame strontia-red; the fused mass reacts alkaline. On charcoal fuses, and in R.F. is converted into a difficultly fusible hepatic mass; this treated with hydrochloric acid and alcohol gives an intensely red flame. With soda on charcoal reacts like barite. Insoluble in acids.

Diff. —Characterized by form; cleavage, high specific gravity, *red* coloration of the blowpipe flame. Does not effervesce with acids like the carbonates (e.g., strontianite); specific gravity lower than that of barite.

Obs.—Usually associated with limestone, or sandstone of various ages; occasionally with metalliferous ores, as with galena and sphalerite at Condorcet, France; at Rezbánya, Hungary; also in beds of gypsum, rock salt, as at Bex, Switzerland; Ischl, Austria; Lüneberg, Hannover; sometimes fills cavities in fossils, e.g., ammonites; with sulphur in some volcanic regions as at Girgenti, Sicily. From Yate, Gloucester, England.

Specimens, finely crystallized, of a bluish tint, are found in limestone about Lake Huron, particularly on Drummond Island, also on Strontian Island, Put-in-Bay, Lake Erie, and at Kingston in Ontario, Canada; Chaumont Bay, Lake Ontario, Schoharie, and Lockport, N. Y. From near Syracuse, N. Y. A blue fibrous celestite occurs at Bell's Mills, Blair Co., Pa. From near Cumberland, Md. In Mineral Co., W. Va., a few miles south of Cumberland, Md., in pyramidal blue crystals. At Tifflin, Ohio. In Texas, at Lampasas, large crystals. With colemanite at Death Valley, San Bernardino Co., Cal. In Canada, in crystalline masses at Kingston, Frontenac Co.; Lansdowne, Leeds Co.; in radiating fibrous masses in the Laurentian of Renfrew Co.

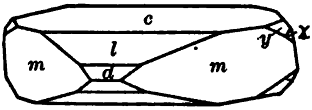
Named from *cœlestis, celestial*, in allusion to the faint shades of blue often present.

Use. — Used in the preparation of strontium nitrate for fireworks; other salts used in the refining of sugar.

ANGLESITE.

Orthorhombic. Axes $a : b : c$ = 0·7852 : 1 : 1·2894.

1007



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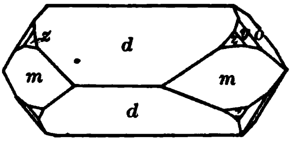
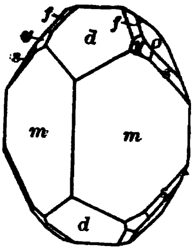


1009



mm''', 110 ∧ $1\bar{1}0$ = 76° 16½'.
cl, 001 ∧ 104 = 22° 19'.
cd, 001 ∧ 102 = 39° 23'.
co, 001 ∧ 011 = 52° 12'.

Crystals sometimes tabular ∥ *c* (001); more often prismatic in habit, and in all the three axial directions, *m* (110), *d* (102), *o* (011), predominating in the different cases; pyramidal of varied types. Also massive, granular to compact; stalactitic; nodular.

Cleavage: *c* (001), *m* (110) distinct, but interrupted. Fracture conchoidal. Very brittle. H. = 2·75–3. G. = 6·3–6·39. Luster highly adamantine in some specimens, in others inclining to resinous and vitreous. Color white, tinged yellow, gray, green, and sometimes blue. Streak uncolored. Transparent to opaque. Optically +. Ax. pl. ∥ *b* (010). Bx ⊥ *a* (100). Dispersion strong, $\rho < v$. 2V = 60°–75°. α = 1·877. β = 1·882. γ = 1·894.

Comp. — Lead sulphate, $PbSO_4$ = Sulphur trioxide 26·4, lead oxide 73·6 = 100.

Pyr., etc. — B.B. decrepitates, fuses in the flame of a candle (F. = 1·5). On charcoal in O.F. fuses to a clear pearl, which on cooling becomes milk-white; in R.F. is reduced with effervescence to metallic lead. With soda on charcoal in R.F. gives metallic lead, and the soda is absorbed by the coal. Difficultly soluble in nitric acid.

Diff.— Characterized by high specific gravity; adamantine luster; cleavage; and by yielding lead B.B. Cerussite effervesces in nitric acid.

Obs. — A result of the decomposition of galena, and often found in its cavities; also surrounds a nucleus of galena in concentric layers. First found in England at Pary's mine in Anglesea; in Derbyshire and in Cumberland in crystals; at Leadhill, Scotland; in Germany at Claustal, in the Harz Mts.; near Siegen in Prussia; Schapbach and Badenweiler in Baden; in Hungary at Felsöbánya and elsewhere; Nerchinsk, Siberia; and at Monte Poni, Sardinia; Granada and Andalusia, Spain; massive in Siberia; in Australia, whence it is exported to England. At Broken Hill, New South Wales. In the Sierra Mojada, Mexico, in immense quantities, mostly massive.

In the United States in crystals at Wheatley's mine, Phenixville, Pa.; in Missouri lead mines; in crystals of varied habit at the Mountain View mine, Carroll Co., Md. In Col. at various points, but less common than cerussite. At the Cerro Gordo mines of Cal. (argentiferous galena), with other lead minerals. In Ariz., in the mines of the Castle Dome district, Yuma Co., and elsewhere. In fine crystals from Kingston and Wardner, Idaho; Eureka, Utah.

Named from the locality, Anglesea, where it was first found.

Use. — An ore of lead.

ANHYDRITE.

Orthorhombic. Axes $a : b : c = 0·8933 : 1 : 1·0008$.

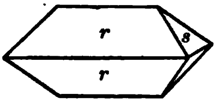
mm''', $110 \wedge 1\bar{1}0 = 83° 33'$ *ss'*, $011 \wedge 0\bar{1}1 = 90° 3'$

rr', $101 \wedge \bar{1}01 = 96° 30'$ *bo*, $010 \wedge 111 = 56° 19'$

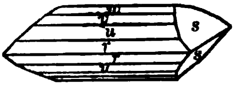
Twins: 1, tw. pl. *d* (012); 2, *r* (101) occasionally as tw. lamellæ. Crystals not common, thick tabular, also prismatic || axis *b*. Usually massive, cleavable, fibrous, lamellar, granular, and sometimes impalpable.

Cleavage: in the three pinacoidal directions yielding rectangular fragments but with varying ease, thus, *c* (001) very perfect; *b* (010) also perfect; *a* (100) somewhat less so. Fracture uneven, sometimes splintery. Brittle. H. = 3–3·5. G. = 2·899–2·985. Luster: *c* pearly, especially after heating in a closed tube; *a* somewhat greasy; *b* vitreous; in massive varieties, vitreous inclining to pearly. Color white, sometimes a grayish, bluish, or reddish tinge; also brick-red. Streak grayish white. Optically +. Ax. pl. || *b* (010). Bx ⊥ *a* (100). 2V = 42°. $\alpha = 1·571$. $\beta = 1·576$. $\gamma = 1·614$.

1010

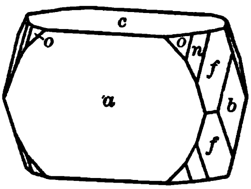


1011



1010, 1011, Stassfurt

1012



1012, Aussee

Var. — 1. *Ordinary*. (*a*) Crystallized; crystals rare, more commonly massive and cleavable in its three rectangular directions. (*b*) Fibrous; either parallel, radiated or plumose. (*c*) Fine granular. (*d*) Scaly granular. *Vulpinite* is a scaly granular kind from Vulpino in Lombardy, Italy; it is cut and polished for ornamental purposes. A kind in contorted concretionary forms is the *tripestone*.

2. *Pseudomorphous;* in cubes after rock-salt.

Comp. — Anhydrous calcium sulphate, $CaSO_4$ = Sulphur trioxide, 58·8, lime 41·2 = 100.

Pyr., etc. — B.B. fuses at 3, coloring the flame reddish yellow, and yielding an enamel-like bead which reacts alkaline. On charcoal in R.F. reduced to a sulphide; with soda does not fuse to a clear globule, and is not absorbed by the coal like barite; is, however, decomposed, and yields a mass which blackens silver. Soluble in hydrochloric acid.

Diff. — Characterized by its cleavage in three rectangular directions (pseudo-cubic in aspect); harder than gypsum; does not effervesce with acids like the carbonates.

Obs. — Occurs in rocks of various ages, especially in limestone strata, and often the same that contain ordinary gypsum, and also very commonly in beds of rock-salt; at the salt mine near Hall in Tyrol, Austria; of Bex, Switzerland; at Aussee, upper Austria, crystallized and massive; Lüneburg, Hannover, Germany; Kapnik in Hungary; Wieliczka in Poland; Ischl in Upper Austria; Berchtesgaden in Bavaria; Stassfurt, Germany, in fine crystals, embedded in kieserite; in cavities in lava at Santorin Island.

In the United States, at Meriden, Conn.; at Lockport, N. Y., fine blue, in geodes of black limestone, with calcite and gypsum; at West Paterson, N. J.; in limestone at Nashville, Tenn., etc. In the salt beds of central Kansas. In Nova Scotia it forms extensive beds.

Anhydrite by absorption of moisture changes to gypsum. Extensive beds are sometimes thus altered in part or throughout, as at Bex, in Switzerland, where, by digging down 60 to 100 ft., the unaltered anhydrite may be found. Sometimes specimens of anhydrite are altered between the folia or over the exterior.

Bassanite. $CaSO_4$. In white opaque crystals having form of gypsum but composed of slender needles in parallel arrangement. These show parallel extinction and positive elongation. G. = 2·69–2·76. Transformed into anhydrite at red heat. Found in blocks ejected from Vesuvius.

Zinkosite. $ZnSO_4$. Reported as occurring at a mine in the Sierra Almagrera, Spain.

Hydrocyanite. $CuSO_4$. Found at Vesuvius as a pale green to blue incrustation after the eruption of 1868.

HOKUTOLITE. A mixture in variable proportions of lead and barium sulphates. A radioactive crystalline crust deposited by hot springs at Hokuto, Formosa.

Millosevichite. Normal ferric and aluminium sulphate. As a violet incrustation, Alum Grotto, Island of Vulcano, Lipari Islands.

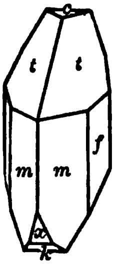
CROCOITE.

Monoclinic. Axes $a : b : c = 0{\cdot}9603 : 1 : 0{\cdot}9159$; $\beta = 77° 33'$.

mm''', $110 \wedge 1\bar{1}0 = 86° 19'$. *tt'*, $111 \wedge 1\bar{1}1 = 60° 50'$.

ck, $001 \wedge \bar{1}01 = 49° 32'$. *ct*, $001 \wedge 111 = 46° 58'$.

1013



Crystals usually prismatic, habit varied. Also imperfectly columnar and granular.

Cleavage: *m* (110) rather distinct; *c* (001), *a* (100) less so. Fracture small conchoidal to uneven. Sectile. H. = 2·5–3. G. = 5·9–6·1. Luster adamantine to vitreous. Color various shades of bright hyacinth-red. Streak orange-yellow. Translucent. $\beta = 2{\cdot}42$.

Comp. — Lead chromate, $PbCrO_4$ = Chromium trioxide 31·1, lead protoxide 68·9 = 100.

Pyr., etc. — In the closed tube decrepitates, blackens, but recovers its original color on cooling. B.B. fuses at 1·5, and on charcoal is reduced to metallic lead with deflagration, leaving a residue of chromium oxide, and giving a lead coating. With salt of phosphorus gives an emerald-green bead in both flames.

Obs. — First found at Berezov, Ural Mts., in crystals in quartz veins; also at Mursinka and near Nizhni Tagilsk in the Ural Mts.; in Brazil, at Congonhas do Campo; at Rezbánya in Hungary, Moldawa in Hungary; on Luzon, one of the Phillippines; in fine crystals from Mt. Dundas, Tasmania; in the Vulture district, Maricopa Co., Ariz.

The name *crocoite* is from *κρόκος*, *saffron*.

Phœnicochroite. Phœnicite. A basic lead chromate, $3PbO.2CrO_3$. In crystals and massive. Color between cochineal- and hyacinth-red. From Berezov in the Ural Mts.

Vauquelinite. A phospho-chromate of lead, perhaps $2(Pb,Cu)CrO_4.(Pb,Cu)_3P_2O_8$. In crystals; also mammillary and reniform. Color green to brown. Index, 1·93. From Berezov in the Ural Mts.

Bellite. Lead chromate containing arsenious oxide. Hexagonal. In aggregates of delicate tuffs. H. = 2·5. G. = 5·5. Color crimson red, yellow to orange. Fusible. From Magnet, Tasmania.

Sulphates with Chlorides, Carbonates, etc. — In part hydrous

LEADHILLITE.

Monoclinic. Axes $a : b : c = 1{\cdot}7476 : 1 : 2{\cdot}2154$; $\beta = 89° 48'$.

mm‴, 110 ∧ 1$\bar{1}$0 = 120° 27′. *cx*, 001 ∧ 111 = 68° 31′.
cw, 001 ∧ 101 = 51° 36′. *cm*, 001 ∧ 110 = 89° 54′.

Twins: tw. pl. *m* (110), analogous to aragonite. Crystals commonly tabular ‖ *c* (001).

Cleavage: *c* (001) very perfect; *a* (100) in traces. Fracture conchoidal, scarcely observable. Rather sectile. H. = 2·5. G. = 6·26–6·44. Luster of *c* pearly, other parts resinous, somewhat adamantine. Color white, passing into yellow, green, or gray. Streak uncolored. Transparent to translucent. Optically –. $\beta = 1{\cdot}93$.

Comp. — Sulphato-carbonate of lead, $4PbO.SO_3.2CO_2.H_2O$ or $PbSO_4.2PbCO_3.Pb(OH)_2$ = Sulphur trioxide 7·4, carbon dioxide 8·2, lead oxide 82·7, water 1·7 = 100.

Pyr., etc. — B.B. intumesces, fuses at 1·5, and turns yellow; but becomes white on cooling. Easily reduced on charcoal. With soda affords the reaction for sulphuric acid. Effervesces briskly in nitric acid, and leaves white lead sulphate undissolved. Yields water in the closed tube.

Obs. — Found at Leadhill, Scotland, with other ores of lead; in England at Red Gill, Cumberland, and at Matlock, Derbyshire. From the Mala-Calzetta lead mine near Iglesias, Sardinia (*maxite*). Observed from Arizona, at the Schulz gold mine with wulfenite, vanadinite, cerussite; partly altered to cerussite. From Tintic district, Utah; from Searchlight, Nev., from Granby, Mo.

SUSANNITE. Regarded at one time as rhombohedral and dimorphous with leadhillite, but probably only a modification of that species. From the Susanna mine, Leadhill, in Scotland.

Sulphohalite. $3Na_2SO_4NaCl.NaF$. In pale greenish yellow octahedrons and dodecahedrons. $n = 1{\cdot}455$. From Borax lake, and Searles lake, San Bernardino Co., Cal.

Caracolite. Perhaps $Pb(OH)Cl.Na_2SO_4$. As a crystalline incrustation. Colorless. From Atacama, Chile.

Kainite. $MgSO_4.KCl.3H_2O$. Usually granular massive and in crusts. Color white to dark flesh-red. Optically –. $\beta = 1{\cdot}506$. From Stassfurt, Germany, and Wolfenbrittel, Brunswick; Kalusz, Galicia.

Connellite. Probably $CuSO_4.2CuCl_2.19Cu(OH)_2.H_2O$. Crystals slender, hexagonal prisms. Color fine blue. Optically +. $\omega = 1{\cdot}724$. From Cornwall, England; from Eureka, Utah; Bisbee, Ariz. *Footeite*, originally described as a hydrous oxychloride of copper from Bisbee, Ariz., is identical with connellite.

Spangolite. A highly basic sulphate of aluminium and copper, $Cu_6AlClSO_{10}.9H_2O$. In dark green hexagonal crystals (hemimorphic), tabular or short prismatic. Usually in very small crystals. From the neighborhood of Tombstone, Ariz.; Clifton and Bisbee, Ariz.; Tintic district, Utah; from Cornwall, England; Sardinia.

Hanksite. $9Na_2SO_4.2Na_2CO_3.KCl$. In hexagonal prisms, short prismatic to tabular; also in quartzoids. Color white to yellow. Optically –. $\omega = 1{\cdot}481$. From Borax Lake, San Bernardino Co., Cal.; also from Death Valley, Inyo Co

B. Acid and Basic Sulphates

Misenite. Probably acid potassium sulphate, $HKSO_4$. In silky fibers of a white color. From Cape Misene, near Naples, Italy.

BROCHANTITE.

Orthorhombic. Axes $a : b : c = 0·7739 : 1 : 0·4871$.

In groups of prismatic acicular crystals (mm''' $110 \wedge 1\bar{1}0 = 75° 28'$ drusy crusts; massive with reniform structure.

Cleavage: b (010) very perfect; m (110) in traces. Fracture uneven. H = 3·5–4. G. = 3·907. Luster vitreous; a little pearly on the cleavage b (101). Color emerald-green, blackish green. Streak paler green. Tra- parent to translucent.

Comp. — A basic sulphate of copper, $CuSO_4.3Cu(OH)_2$ or $4CuO.S$ $3H_2O$ = Sulphur trioxide 17·7, cupric oxide 70·3, water 12·0 = 100.

Pyr., etc. — Yields water, and at a higher temperature sulphuric acid, in the closed and becomes black. B.B. fuses, and on charcoal affords metallic copper. With soda g the reaction for sulphuric acid.

Obs. — Occurs in the Ural Mts.; the königine (or *königite*) was from Gumeshev Ural Mts.; in England near Roughten Gill, in Cumberland and in Cornwall (in part *wa- tonite*); at Rezbánya, Hungary; in small beds at Krisuvig in Iceland (*krisuvigite* Mexico (*brongnartine*); Atacama and Tarapacá, Chile. In the United States, at Mona mine, Chaffee Co., Col.; in Utah, at Frisco, in Tintic district, at the Mammoth mine Clifton-Morenci district, and Bisbee, Ariz.

Lanarkite. Basic lead sulphate, Pb_2SO_5. In monoclinic crystals. Color green- white, pale yellow or gray. From Leadhill, Scotland; Siberia; the Harz Mts., German

Dolerophanite. A basic cupric sulphate, Cu_2SO_5(?). In small brown monocli crystals. From Vesuvius (eruption of 1868).

Caledonite. A basic sulphate of lead and copper, perhaps $2(Pb,Cu)O.SO_3.H_2O$. Said at times to contain CO_2. In small prismatic orthorhombic crystals. Color deep verdigri- green or bluish green. Index, 1·85. From Leadhill, Scotland; Red Gill, Cumberland, etc., England; Inyo Co., Cal.; Organ Mts., N. M.; Butte, Mon.; Atacama, Chile; New Caledonia.

Linarite. A basic sulphate of lead and copper, $(Pb,Cu)SO_4.(Pb,Cu)(OH)_2$. In deep blue monoclinic crystals. Optically −. $\beta = 1·838$. From Leadhill, Scotland; Cumberland, England; the Ural Mts.; Broken Hill, New South Wales; Sardinia. Also Inyo Co., Cal.; Eureka, Utah; Schulz, Ariz.; Slocan, British Columbia.

Antlerite. Perhaps $CuSO_4.2Cu(OH)_2$. In light green soft lumps. From the Antler mine, Mohave Co., Ariz. *Stelznerite* from Remolinos, Vallinar, Chile, is probably the same as antlerite. In prismatic crystals. G. = 3·9.

Alumian. Perhaps $Al_2O_3.2SO_3$. White crystalline or massive. Sierra Almagrera, Spain.

C. Normal Hydrous Sulphates

Three well-characterized groups are included here. Two of these, the EPSOMITE GROUP and the MELANTERITE GROUP, have the same general formula, $RSO_4.7H_2O$, but in the first the crystallization is orthorhombic, in the second monoclinic. The species are best known from the artificial crystals of the laboratory; the native minerals are rarely crystallized. There is also the isometric ALUM GROUP, to which the same remark is applicable.

Lecontite. $(Na,NH_4,K)_2SO_4.2H_2O$. From bat guano in the cave of Las Piedras, near Comayagua, Central America.

MIRABILITE. Glauber Salt.

Monoclinic. Crystals like pyroxene in habit and angle. Usually in efflorescent crusts.

Cleavage: a (100), perfect; c (001), b (010) in traces. H. = 1·5–2. G. = 1·481. Luster vitreous. Color white. Transparent to opaque. Taste cool, then feebly saline and bitter. Optically −. 2V = 76°. $\alpha = 1{\cdot}396$. $\beta = 1{\cdot}410$. $\gamma = 1{\cdot}419$.

Comp. — Hydrous sodium sulphate, $Na_2SO_4.10H_2O$ = Sulphur trioxide 24·8, soda 19·3, water 55·9 = 100.

Pyr., etc. — In the closed tube much water; gives an intense yellow to the flame. Very soluble in water. Loses its water on exposure to dry air and falls to powder.

Obs. — Occurs at Ischl, Hallstadt, and Aussee in Upper Austria; also in Hungary, Switzerland, Italy; at the hot springs at Carlsbad, Bohemia, etc. Large quantities of this sodium sulphate are obtained from the waters of Great Salt Lake, Utah.

Kieserite. $MgSO_4.H_2O$. Monoclinic. Usually massive, granular to compact. Color white, grayish, yellowish. Optically +. $\beta = 1{\cdot}535$. From Stassfurt, Germany; Hallstadt, Austria; India.

Szomolnokite. $FeSO_4.H_2O$. Monoclinic. Isomorphous with *kieserite*. In pyramids. G. = 3·08. Color yellow or brown. Found with other iron sulphates from Szomolnok, Hungary. Apparently identical with *ferropallidite* from near Copiapo, Chile.

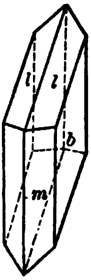
Szmikite. $MnSO_4.H_2O$. Stalactitic. Whitish, reddish. From Felsöbánya, Hungary.

GYPSUM.

Monoclinic. Axes $a : b : c = 0{\cdot}6899 : 1 : 0{\cdot}4124$; $\beta = 80°\ 42'$.

mm''', $110 \wedge 1\bar{1}0 = 68°\ 30'$.
cd, $001 \wedge 101 = 28°\ 17'$.
ct, $001 \wedge \bar{1}01 = 33°\ 8\frac{1}{2}'$.
ce, $001 \wedge \bar{1}03 = 11°\ 29'$.
vv', $011 \wedge 0\bar{1}1 = 44°\ 17\frac{1}{2}'$.
ll', $111 \wedge 1\bar{1}1 = 36°\ 12'$.
nn', $\bar{1}11 \wedge \bar{1}\bar{1}1 = 41°\ 20'$.
ml, $110 \wedge 111 = 49°\ 9'$.
mn, $110 \wedge \bar{1}11 = 59°\ 15'$.

1014



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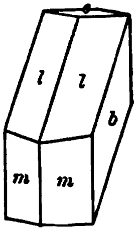
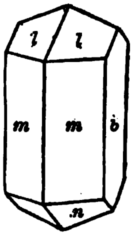


1016



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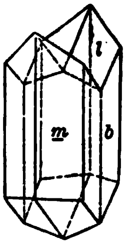
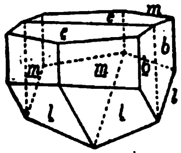


1018

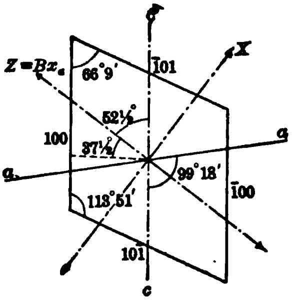


Crystals usually simple in habit, common form flattened ‖ *b* (010) or prismatic to acicular ‖ *c* axis; again prismatic by extension of *l* (111). Also lenticular by rounding of *l* (111) and *e* ($\bar{1}03$). The form *e* ($\bar{1}03$), whose faces are usually rough and convex, is nearly at right angles to the vertical axis (edge *m* (110)/*m'''* ($1\bar{1}0$), hence the apparent hemimorphic character of the twin (Fig. 1018). Simple crystals often with warped as well as curved surfaces. Also foliated massive; lamellar-stellate; often granular massive; and sometimes nearly impalpable. Twins: tw. pl. *a* (100), very common, often the familiar swallow-tail twins.

Cleavage: *b* (010) eminent, yielding easily thin polished folia; *a* (100), giving a surface with conchoidal fracture; *n* ($\bar{1}11$), with a fibrous fracture ‖ *t*($\bar{1}01$); a cleavage fragment has the rhombic form of Fig. 1019, with plane angles of 66° and 114°. H. = 1·5–2. G. = 2·314–2·328, when in pure crystals. Luster of *b* (010) pearly and shining, other faces subvitreous. Massive varieties often glistening, sometimes dull earthy. Color usually white; sometimes gray, flesh-red, honey-yellow, ocher-yellow, blue; impure varieties often black, brown, red, or reddish brown. Streak white. Transparent to opaque.

Optically +. Ax. pl. || *b* (010), and Bx ∧ *c* axis = + 52½° (at 9·4° C.) (cf. Fig. 1019). Dispersion $\rho > v$; also inclined strong. $Bx_r \wedge Bx_{bl}$ = 0° 30′. 2V = 58°. $\alpha = 1{\cdot}520$. $\beta = 1{\cdot}523$. $\gamma = 1{\cdot}530$. On the effect of heat on the optical properties, see p. 297.

1019



Var. — 1. *Crystallized*, or *Selenite;* colorless, transparent; in distinct crystals, or broad folia, often large. Usually flexible and yielding a fibrous fracture || *t* (1̄01), but the variety from Montmartre near Paris, France, rather brittle.

2. *Fibrous;* coarse or fine. Called *Satin spar*, when fine-fibrous, with pearly opalescence.

3. *Massive; Alabaster*, a fine-grained variety, white or delicately shaded; *earthy* or *rock-gypsum*, a dull-colored rock, often impure with clay, calcium carbonate or silica.

Also, in caves, curious curved forms, often grouped in rosettes and other shapes.

Comp. — Hydrous calcium sulphate, $CaSO_4.2H_2O$ = Sulphur trioxide 46·6, lime 32·5, water 20·9 = 100.

Pyr., etc. — In the closed tube gives off water and becomes opaque. Fuses at 2·5–3, coloring the flame reddish yellow. For other reactions see Anhydrite, p. 629. Ignited at a temperature not exceeding 260° C., it again combines with water when moistened, and becomes firmly solid. Soluble in hydrochloric acid, and also in 400 to 500 parts of water.

Diff. — Characterized by its softness in all varieties, and by cleavages in crystallized kinds; it does not effervesce with acids like calcite, nor gelatinize like the zeolites; harder than talc and yields much water in the closed tube.

Obs. — Gypsum often forms extensive beds in connection with various stratified rocks, especially limestones, and marlites or clay beds. It occurs occasionally in crystalline rocks. It is also a product of volcanoes, occurring about fumaroles, or where sulphur gases are escaping, being formed from the sulphuric acid generated, and the lime afforded by the decomposing lavas. It is also produced by the decomposition of pyrite when lime is present. Gypsum is also deposited on the evaporation of sea-water and brines, in which it exists in solution.

Fine specimens are found in the salt mines of Bex in Switzerland; Hall in Tyrol, Austria; the sulphur mines of Sicily; in the clay of Shotover Hill, near Oxford, England; and large lenticular crystals at Montmartre, near Paris, France. A noted locality of alabaster occurs at Castelino, 35 m. from Leghorn, Italy, whence it is taken to Florence for the manufacture of vases, figures, etc.

Occurs in extensive beds in several of the United States, and more particularly N. Y., Iowa, Mich., Okla., Texas, Ohio, and Ark., and is usually associated with salt springs, also with rock salt. Also on a large scale in Nova Scotia, etc.

Handsome selenite and snowy gypsum occur in N. Y., near Lockport in limestone. In Md., large grouped crystals on the St. Mary's in clay. In Ohio, large transparent crystals have been found at Ellsworth and Canfield, Trumbull Co. In Tenn., selenite and alabaster in Davidson Co. In Ky., in Mammoth Cave, it has the forms of rosettes, or flowers, vines, and shrubbery. Also common in isolated crystals and masses, in the Cretaceous clays in the western United States. In enormous crystals, several feet in length, in Wayne Co., Utah. In Nova Scotia, in Sussex, Kings Co., large single and grouped crystals, which mostly contain much symmetrically disseminated sand.

Named from γύψος, the Greek for the mineral, but more especially for the *calcined* mineral. The derivation ordinarily suggested, from γῆ, *earth*, and ἕψειν, *to cook*, corresponds with this, the most common use of the word among the Greeks.

Burnt gypsum is called *Plaster-of-Paris*, because the Montmartre gypsum quarries, near Paris, are, and have long been, famous for affording it.

Use. — In the manufacture of plaster-of-Paris used for molds and casts and as "staff" in erection of temporary buildings; in making adamant plaster for interior use; as land plaster for fertilizer; as alabaster for ornamental purposes.

Ilesite. $(Mn,Zn,Fe)SO_4.4H_2O$. In loosely adherent aggregates. Color clear green. From Colorado.

Epsomite Group. $RSO_4.7H_2O$. Orthorhombic

Epsomite	$MgSO_4.7H_2O$ $(Fe,Mg)SO_4.7H_2O$	$a : b : c$ = 0·9902 : 1 : 0·5709
Goslarite	$ZnSO_4.7H_2O$	0·9807 : 1 : 0·5631
Ferro-goslarite	$(Zn,Fe)SO_4.7H_2O$	
Morenosite	$NiSO_4.7H_2O$	0·9816 : 1 : 0·5655

EPSOMITE. Epsom Salt.

Orthorhombic. Usually in botryoidal masses and delicately fibrous crusts. Cleavage: *b* (010) very perfect. Fracture conchoidal. H. = 2·0–2·5. G. = = 1·751. Luster vitreous to earthy. Streak and color white. Transparent to translucent. Taste bitter and saline. Optically −. 2V = 52°. α = 1·433. β = 1·455. γ = 1·461.

Comp. — Hydrous magnesium sulphate, $MgSO_4.7H_2O$ = Sulphur trioxide 32·5, magnesia 16·3, water 51·2 = 100.

Obs. — Common in mineral waters, and as a delicate fibrous or capillary efflorescence on rocks, in the galleries of mines, and elsewhere. In the former state it exists at Epsom, England, and at Sedlitz and Saidschitz (or Saidschütz) in Bohemia. At Idria in Carniola, Austria, it occurs in silky fibers, and is hence called *hairsalt* by the workmen. Also obtained at the gypsum quarries of Montmartre, near Paris. Also found at Vesuvius, at the eruptions of 1850 and 1855.

The floors of the limestone caves of Kentucky, Tennessee, and Indiana, are in many instances covered with epsomite, in minute crystals, mingled with the earth. In the Mammoth Cave, Ky., it adheres to the roof in loose masses like snowballs. From Laramie Basin, Wy.; near Leona Heights, Alameda Co., Cal.; Cripple Creek, Col.

Goslarite. $ZnSO_4.7H_2O$. Commonly massive. Color white, reddish, yellowish. Optically −. β = 1·480. Formed by the decomposition of sphalerite, and found in the passages of mines, as at the Rammelsberg mine near Goslar, in the Harz Mts., Germany, etc. In Mon. at the Gagnon mine, Butte. *Ferro-goslarite* (4·9 p. c. $FeSO_4$) occurs with sphalerite at Webb City, Jasper Co., Mo. *Cuprogoslarite* (13·4 p. c. $CuSO_4$) occurs as a light greenish blue incrustation on the wall of an abandoned zinc mine at Galena, Kan.

Morenosite. $NiSO_4.7H_2O$. In acicular crystals; also fibrous, as an efflorescence. Color apple-green to greenish white. β = 1·489. A result of the alteration of nickel ores, as near Cape Hortegal, in Galicia; Riechelsdorf, in Hesse, Germany; Zermatt, Switzerland, containing magnesium.

Melanterite Group. $RSO_4.7H_2O$. Monoclinic

		$a : b : c$	
Melanterite	$FeSO_4.7H_2O$	1·1828 : 1 : 1·5427	β = 75° 44′
Luckite	$(Fe,Mn)SO_4.7H_2O$		
Mallardite	$MnSO_4.7H_2O$		
Pisanite	$(Fe,Cu)SO_4.7H_2O$	1·1609 : 1 : 1·5110	74° 38′
Bieberite	$CoSO_4.7H_2O$	1·1815 : 1 : 1·5325	75° 20′
Cupromagnesite	$(Cu,Mg)SO_4.7H_2O$		
Boothite	$CuSO_4.7H_2O$	1·1622 : 1 : 1·500	74° 24′
Chalcanthite	$CuSO_4.5H_2O$	Triclinic	

$a : b : c$ = 0·5656 : 1 : 0·5507; α = 82° 21′, β = 73° 11′, γ = 77° 37′.

The species here included are the ordinary vitriols. They are identical in general formula with the species of the Epsomite group, and are regarded as the same compound essentially under oblique crystallization. The copper sulphate, chalcanthite, diverges from the others in crystallization, and contains but 5 molecules of water.

MELANTERITE. Copperas.

Monoclinic. Usually capillary, fibrous, stalactitic, and concretionary; also massive, pulverulent. Cleavage: *c* (001) perfect; *m* (110) less so. Fracture conchoidal. Brittle. H. = 2. G. = 1·89–1·90. Luster vitreous. Color various shades of green, passing into white; becoming yellowish on exposure. Streak uncolored. Subtransparent to translucent. Taste sweetish, astringent, and metallic. Optically +. 2V = 86°. α = 1·471. β = 1·478. γ = 1·486.

Comp. — Hydrous ferrous sulphate, $FeSO_4.7H_2O$ = Sulphur trioxide 28·8, iron protoxide 25·9, water 45·3 = 100. Manganese and magnesium sometimes replace part of the iron.

Obs. Proceeds from the decomposition of pyrite or marcasite; thus near Goslar in the Harz Mts., Germany; Bodenmais in Bavaria; Falun, Sweden, and elsewhere. Usually accompanies pyrite in the United States, as an efflorescence. In crystals from near Leona Heights, Alameda Co., Cal. *Luckite* (1·9 p. c. MnO) is from the "Lucky Boy" mine, Butterfield Cañon, Utah.

Mallardite. $MnSO_4.7H_2O$. Fibrous, massive; colorless. From the mine "Lucky Boy," south of Salt Lake, Utah.

Pisanite. $(Fe,Cu)SO_4.7H_2O$. CuO 10 to 15 p. c. In concretionary and stalactitic forms. Color blue. From Turkey. From Bingham, Utah; Ducktown, Tenn.; near Leona Heights, Cal.

SALVADORITE. A copper-iron vitriol near pisanite. From the Salvador mine Quetena, Chile.

Bieberite. $CoSO_4.7H_2O$. Usually in stalactites and crusts. Color flesh- and rose-red. From Bieber, in Hesse, Germany, etc.

Boothite. $CuSO_4.7H_2O$. Usually massive. H. = 2–2·5. G. = 1·94. Color blue, paler than chalcanthite. Found at Alma pyrite mine, near Leona Heights, Alameda Co., and at a copper mine near Campo Seco, Calaveras Co., Cal.

CUPROMAGNESITE. $(Cu,Mg)SO_4.7H_2O$. From Vesuvius.

CHALCANTHITE. Blue Vitriol.

Triclinic. Crystals commonly flattened || *p* (111). Occurs also massive, stalactitic, reniform, sometimes with fibrous structure.

Cleavage: *M* (1$\bar{1}$0), *m* (110), *p* (111) imperfect. Fracture conchoidal. Brittle. H. = 2·5. G. = 2·12–2·30. Luster vitreous. Color Berlin-blue to sky-blue, of different shades; sometimes a little greenish. Streak uncolored. Subtransparent to translucent. Taste metallic and nauseous. Optically –. 2V = 56°. α = 1·516. β = 1·539. γ = 1·546.

Comp. — Hydrous cupric sulphate, $CuSO_4.5H_2O$ = Sulphur trioxide 32·1, cupric oxide 31·8, water 36·1 = 100.

Pyr., etc. — In the closed tube yields water, and at a higher temperature sulphur trioxide. B.B. with soda on charcoal yields metallic copper. With the fluxes reacts for copper. Soluble in water; a drop of the solution placed on a surface of iron coats it with metallic copper.

Obs. — Found in waters issuing from mines and in connection with rocks containing chalcopyrite, by the alteration of which it is formed; thus at the Rammelsberg mine near Goslar in the Harz Mts., Germany; Falun in Sweden; Parys mine, Anglesea, England; at various mines in County Wicklow, Ireland; Rio Tinto mine, Spain; Zaječar, Servia. From the Hiwassee copper mine, also in large quantities at other mines, in Polk Co., Tenn. In Ariz., near Clifton, Graham Co., and Jerome, Yavapai Co.; in Cal. near Leona Heights, Alameda Co.; from Ely and Reno, Nev.

Syngenite. Kaluzite. $CaSO_4.K_2SO_4.H_2O$. In prismatic (monoclinic) crystals. Colorless or milky-white. β = 1·517. From Kalusz, Galicia.

Löweite. $MgSO_4.Na_2SO_4.2\frac{1}{2}H_2O$. Tetragonal. Massive, cleavable. Color pale yellow. Index, 1·49. From Ischl, Austria.

Blödite. $MgSO_4.Na_2SO_4.4H_2O$. Crystals short prismatic, monoclinic; also massive granular or compact. Colorless to greenish, yellowish, red. Optically −. $\beta = 1{\cdot}488$. From the salt mines of Ischl and at Hallstadt (*simonyite*), Austria; at Stassfurt, Germany; the salt lakes of Astrakhan (*astrakanite*), Asia; India; Chile, etc. From Soda Lake, San Luis Obispo Co., Cal.

Leonite. $MgSO_4.K_2SO_4.4H_2O$. In monoclinic crystals from Westeregeln and Leopoldshall, Germany. $\beta = 1{\cdot}487$.

Boussingaultite. $(NH_4)_2SO_4.MgSO_4.6H_2O$. From the boric acid lagoons, Tuscany, Italy. Index, 1·474.

Picromerite. $MgSO_4.K_2SO_4.6H_2.O$. As a white crystalline incrustation. Monoclinic. Optically +. $\beta = 1{\cdot}463$. From Vesuvius with *cyanochroite*, an isomorphous species in which copper replaces the magnesium. Also at Stassfurt (*schoenite*) and Aschersleben, Germany; Galusz in East Galicia.

Polyhalite. $2CaSO_4.MgSO_4.K_2SO_4.2H_2O$. Triclinic. Usually in compact fibrous or lamellar masses. Color flesh- or brick-red. Optically −. $\beta = 1{\cdot}562$. Occurs at the mines of Ischl, Hallstadt, etc., in Austria; in Germany at Berchtesgaden, Bavaria; Stassfurt, Prussia.

Hexahydrite. $MgSO_4.6H_2O$. Columnar to fibrous structure. Cleavage prismatic. G. = 1·76. Color, white with light green tone. Pearly luster. Opaque. Salty, bitter taste. B.B. exfoliates and yields water but does not fuse. Found in Lillooet district, British Columbia.

Alum Group. Isometric

$$\overset{\text{I}}{R}Al(SO_4)_2.12H_2O \text{ or } \overset{\text{I}}{R}_2SO_4.Al_2(SO_4)_3.24H_2O.$$

Kalinite	Potash Alum	$KAl(SO_4)_2.12H_2O$
Tschermigite	Ammonia Alum	$(NH_4)Al(SO_4)_2.12H_2O$
Mendozite	Soda Alum	$NaAl(SO_4)_2.12H_2O$

The ALUMS proper are isometric in crystallization and, chemically, are hydrous sulphates of aluminium with an alkali metal and 12 (i.e., if the formula is doubled, 24) molecules of water. The species listed above occur very sparingly in nature, and are best known in artificial form in the laboratory.

The HALOTRICHITES are oblique in crystallization, very commonly fibrous in structure, and are hydrous sulphates of aluminium with magnesium, manganese, etc.; the amount of water in some cases is given as 22 molecules, and in others 24, but it is not always easy to decide between the two. Here belong:

Pickeringite. Magnesia Alum. $MgSO_4.Al_2(SO_4)_3.22H_2O$. In long fibrous masses; and in efflorescences.

Halotrichite. Iron Alum. $FeSO_4.Al_2(SO_4)_3.24H_2O$. In yellowish silky fibrous forms. Index, 1.48.

Bilinite. $FeSO_4.Fe_2(SO_4)_3.24H_2O$. Radiating fibrous. Color white to yellow. From Schwaz, near Bilin, Bohemia.

Apjohnite. Manganese Alum. $MnSO_4.Al_2(SO_4)_3.24H_2O$. *Bushmanite* contains MgO. In fibrous or asbestiform masses; also as crusts and efflorescences.

Dietrichite. $(Zn,Fe,Mn)SO_4.Al_2(SO_4)_3.22H_2O$.

Coquimbite. $Fe_2(SO_4)_3.9H_2O$. Rhombohedral. Granular massive. Color white, yellowish, brownish. Optically +. $\omega = 1{\cdot}550$. From the Tierra Amarilla near Copiapo, Chile (not from Coquimbo).

Quenstedtite. $Fe_2(SO_4)_3.10H_2O$. In reddish tabular crystals. With coquimbite, Chile.

Ihlëite. $Fe_2(SO_4)_3.12H_2O$? An orange yellow efflorescence on graphite. From grau, Bohemia. Perhaps identical with *copiapite*.

Alunogen. $Al_2(SO_4)_3.18H_2O$. Usually in delicate fibrous masses or crusts; mas- Color white, or tinged with yellow or red. From near Bilin, Bohemia; Bodenmais, many; Pusterthal, Tyrol, Austria; from Vesuvius; Elba. From Cripple Creek, Dou Springs, and Alum Gulch, Col.

DOUGHTYITE. A hydrated aluminium sulphate deposited by the alkaline waters Doughty Springs in Col.

Kröhnkite. $CuSO_4.Na_2SO_4.2H_2O$. Monoclinic crystalline; massive, coarsely fib Color azure-blue. Optically −. $\beta = 1·577$. From Calama, Atacama, Chuquicam Autofagasta, and Collahurasi, Tarapacá, Chile.

Natrochalcite. $Cu_4(OH)_2(SO_4)_2.Na_2SO_4.2H_2O$. Monoclinic. Habit pyramidal. P- fect basal cleavage. H. = 4·5. G. = 2·3. Color bright emerald-green. $\beta = 1$ Found at Chuquicamata, Autofagasta, Chile.

PHILLIPITE. Perhaps $CuSO_4.Fe_2(SO_4)_3.nH_2O$. In blue fibrous masses. Found at copper mines in the Cordilleras of Condes, province of Santiago, Chile.

Ferronatrite. $3Na_2SO_4.Fe_2(SO_4)_3.6H_2O$. Rhombohedral. Rarely in acicular cryst. usually in spherical forms. Color greenish or gray to white. Optically +. $\omega = 1·5$ From Sierra Gorda near Caracoles, Chile.

Römerite. $FeSO_4.Fe_2(SO_4)_3.14H_2O$. In tabular triclinic crystals; granular, massive. Color chesnut-brown. From Goslar in the Harz Mts., Germany; Persia; Chile.

Basic Hydrous Sulphates

Langite. Near brochantite. $CuSO_4.3Cu(OH)_2.H_2O$. Usually in fibro-lamellar, concretionary crusts. Color blue to greenish blue. From Cornwall.

Herrengrundite. $2(CuOH)_2SO_4.Cu(OH)_2.3H_2O$ with one-fifth of the copper replaced by calcium. In thin tabular monoclinic crystals; usually in spherical groups. Color emerald-green, bluish green. From Herrengrund, Hungary.

Vernadskite. $3CuSO_4.Cu(OH)_2.4H_2O$. In aggregates of minute crystals. H. = 3·5. Occurs as an alteration of *dolerophanite* at Vesuvius.

Kamarezite. A hydrous basic copper sulphate from Laurion, Greece.

Cyanotrichite. Lettsomite. Perhaps $4CuO.Al_2O_3.SO_3.8H_2O$. In velvet-like druses; in spherical forms. Color bright blue. From Moldawa in the Banat, Hungary; Cap Garonne, France. In Utah and Arizona.

Serpierite. A basic sulphate of copper and zinc. In minute crystals, tabular, in tufts. Color bluish green. From Laurion, Greece.

Beaverite. $CuO.PbO.Fe_2O_3.2SO_3.4H_2O$. Hexagonal? In microscopic plates. Color, canary-yellow. Refractive index > 1·74. From Horn Silver mine, Frisco, Beaver Co., Utah.

Vegasite. $PbO.3Fe_2O_3.3SO_3.6H_2O$. Hexagonal. In microscopic fibrous crystals, sometimes showing hexagonal plates. Optically −. Indices, 1·75–1·82. Found in Yellow Pine district, near Las Vegas, Nev.

COPIAPITE.

Monoclinic. Usually in loose aggregations of crystalline scales, or granular massive; incrusting.

Cleavage: *b* (010). H. = 2·5. G. = 2·103. Luster pearly. Color sulphur-yellow, citron-yellow. Translucent. Optically −. $\alpha = 1·527$. $\beta = 1·547$. $\gamma = 1·572$.

Comp. — A basic ferric sulphate, perhaps $2Fe_2O_3.5SO_3.18H_2O$ = Sulphur trioxide 38·3, iron sesquioxide 30·6, water 31·1 = 100.

Misy is an old term, which has been somewhat vaguely applied. It seems to belong in part here and in part also to other related species. *Janosite* is identical with copiapite.

Pyr., etc. — Yields water, and at a higher temperature sulphuric acid. On charcoal becomes magnetic, and with soda affords the reaction for sulphuric acid. With the fluxes reacts for iron. Soluble in water, and decomposed by boiling water.

Obs. — The original copiapite was from Copiapo, Chile. Also from Elba and from near Leona Heights, Alameda Co., Cal.

Other hydrated ferric sulphates:

Castanite. $Fe_2O_3.2SO_3.8H_2O$. Color chestnut-brown. From Sierra Gorda, Chile.

Utahite. $3Fe_2O_3.2SO_3.7H_2O$. In aggregates of fine scales. Color orange-yellow. From the Tintic district, Utah; Guanaco, Taltal, Chile. Perhaps identical with *carphosiderite*.

Amarantite. $Fe_2O_3.2SO_3.7H_2O$. Triclinic. Usually in columnar or bladed masses, also radiated. Color amaranth-red. From near Caracoles, Chile. *Hohmannite* is the same partially altered; this is probably also true of *paposite*.

Fibroferrite. $Fe_2O_3.2SO_3.10H_2O$. Orthorhombic. In delicately fibrous aggregates. Color pale yellow, nearly white. From the Tierra Amarilla near Copiapo, Chile.

Raimondite. $2Fe_2O_3.3SO_3.7H_2O$. In thin six-sided tables. Color between honey- and ocher-yellow. From the tin mines of Ehrenfriedersdorf; mines of Bolivia. Perhaps identical with *carphosiderite*.

Carphosiderite. $3Fe_2O_3.4SO_3.7H_2O$. In reniform masses, and incrustations; also in micaceous lamellæ. Color straw-yellow. From Greenland. *Utahite, apatelite, raimondite* and *cyprusite* are probably identical with *carphosiderite*.

Planoferrite. $Fe_2O_3.SO_3.15H_2O$. Orthorhombic? In rhombic or hexagonal plates. Yellowish green to brown. From near Morro Moreno, Autofagasta, Chile.

Glockerite. $2Fe_2O_3.SO_3.6H_2O$. Massive, sparry or earthy; stalactitic. Color brown to ocher-yellow to pitch-black; dull green. From Goslar, Harz Mts., Germany.

Knoxvillite. A hydrous basic sulphate of chromium, ferric iron, and aluminium. In rhombic plates. Color greenish yellow. From the Redington mercury mine, Knoxville, Cal.

REDINGTONITE. A hydrous chromium sulphate, in finely fibrous masses of a pale purple color. From Redington mercury mine, Knoxville, Cal.

Cyprusite. Perhaps $7Fe_2O_3.Al_2O_3.10SO_3.14H_2O$. An aggregation of microscopic crystals. Color yellowish. From the island of Cyprus. Perhaps identical with *carphosiderite*.

Aluminite (Websterite). $Al_2O_3.SO_3.9H_2O$. Usually in white earthy reniform masses, compact. Index, 1·48. From near Halle, Germany, in clay; also at Newhaven, Sussex, England, and elsewhere.

Paraluminite. Near aluminite, but supposed to be $2Al_2O_3.SO_3.15H_2O$.

Felsöbányite. $2Al_2O_3.SO_3.10H_2O$. Massive; in scaly concretions. Color snow-white. From near Felsöbánya, Hungary.

Botryogen. Perhaps $MgO.FeO.Fe_2O_3.4SO_3.18H_2O$. Monoclinic. Usually in reniform and botryoidal shapes. Color deep hyacinth-red, ocher-yellow. $\beta = 1{\cdot}548$. From Falun, Sweden; also from Persia; from Lake and Napa Cos., Cal.

Sideronatrite. $2Na_2O.Fe_2O_3.4SO_3.7H_2O$. Fibrous, massive. Color yellow. From the province of Tarapacá, Chile. Also on the Urus plateau, near Sarakaya, on the island, Cheleken, in the Caspian Sea (*urusite*).

Voltaite. Perhaps $3(K_2,Fe)O.2(Al,Fe)_2O_3.6SO_3.9H_2O$. In octahedrons, etc. Color dull oil-green to brown or black. From the solfatara near Naples; Schmölnitz, Hungary; also Persia.

Metavoltine. Perhaps $5(K_2,Na_2,Fe)O.3Fe_2O_3.12SO_3.18H_2O$. In aggregates of minute yellow scales. Occurs with voltaite in Persia. From Vesuvius; found in fumeroles on islands of Milo and Vulcano; from Miseno, Italy.

ALUNITE. Alumstone.

Rhombohedral. Axis $c = 1{\cdot}2520$. In rhombohedrons, resembling cubes (*rr'* $10\bar{1}1 \wedge \bar{1}101 = 90° 50'$). Also massive, having a fibrous, granular, or impalpable texture.

Cleavage: *c* (0001) distinct; *r* (10$\bar{1}$1) in traces. Fracture flat conchoidal to uneven; of massive varieties splintery; and sometimes earthy. Brittle. H. = 3·5–4. G. = 2·58–2·752. Luster of *r* vitreous, basal plane somewhat pearly. Color white, sometimes grayish or reddish. Streak white. Transparent to subtranslucent. Optically +. ω = 1·572. ε = 1·592.

Comp. — Basic hydrous sulphate of aluminium and potassium, $K_2Al_6(OH)_{12}(SO_4)_4$ = Sulphur trioxide 38·6, alumina 37·0, potash 11·4, water 13·0 = 100. Sometimes contains considerable soda, *natroalunite.*

Pyr., etc. — B.B. decrepitates, and is infusible. In the closed tube yields water, sometimes also ammonium sulphate, and at a higher temperature sulphurous and sulphuric oxides. Heated with cobalt solution affords a fine blue color. With soda and charcoal infusible, but yields a hepatic mass. Soluble in sulphuric acid.

Obs. — Forms seams in trachytic and allied rocks, where it has been formed as a result of the alteration of the rock by means of sulphurous vapors; as at Tolfa, near Civitavecchia, Italy; in Hungary; on Milo, Grecian Archipelago; at Mt. Dore, France; Kinkwaseki, Formosa. In the United States, associated with diaspore, in rhombohedral crystals, tabular through the presence of *c* (0001) at the Rosita Hills, Custer Co., and from Red Mt., Col.; Marysvale, Utah; Goldfield and near Sulphur, Nev.

JAROSITE.

Rhombohedral. Axis *c* = 1·2492; *rr'* 10$\bar{1}$1 ∧ $\bar{1}$101 = 90° 45', *cr* 0001 ∧ 10$\bar{1}$1 = 55° 16'. Often in druses of minute crystals; also fibrous, granular massive; in nodules, or as an incrustation.

Cleavage: *c* (0001) distinct. Fracture uneven. Brittle. H. = 2·5–3·5. G. = 3·15–3·26. Luster vitreous to subadamantine: brilliant, also dull. Color ocher-yellow, yellowish brown, clove-brown. Streak yellow, shining. Optically +. ω = 1·74. ε = 1·77.

Comp. — $K_2Fe_6(OH)_{12}(SO_4)_4$ = Sulphur trioxide 31·9, iron sesquixoide 47·9, potash 9·4, water 10·8 = 100.

Obs. — The original Gelbeisenerz was from Luschitz, between Kolosoruk and Bilin, Bohemia, in brown coal; and later from Modum, Norway, in alum slate. The jarosite was from Barranco Jaroso, in the Sierra Almagrera, Spain; Schlaggenwald, Bohemia; Elba; Chocaya, Potosi, Bolivia. In the United States on quartz in the Vulture mine, Ariz.; in Chaffee County, Col.; Tintic district, Utah; Lawrence Co., S. D.; Dona Ana Co., N. M.; Bisbee, Ariz.; Brewster Co., Texas.

Natrojarosite. $Na_2Fe_6(OH)_{12}(SO_4)_4$. Rhombohedral. In minute tabular crystals. Color yellow-brown. From Soda Springs Valley, Esmeralda Co., Nev.

Plumbojarosite. $PbFe_6(OH)_{12}(SO_4)_4$. Rhombohedral. In minute tabular crystals. Color dark brown. From Cook's Peak, N. M., and in Beaver County, Utah.

Palmierite. $3(K,Na)_2SO_4.4PbSO_4$? In microscopic plates, often hexagonal in outline. Colorless. Fusible. Found in fumerole deposits at Vesuvius.

Löwigite. Perhaps $K_2O.3Al_2O_3.4SO_3.9H_2O$. In rounded masses, similar to compact alunite. Found in a coal bed at Tabrze in Upper Silesia; Mt. Kinjal, Northern Caucasia; also with alunite at Tolfa, Italy.

ALMERIITE. $Na_2SO_4.Al_2(SO_4)_3.5Al(OH)_3.H_2O$. Compact. White. From Almeria, Spain.

Ettringite. Perhaps $6CaO.Al_2O_3.3SO_3.33H_2O$. In minute colorless acicular crystals. From limestone-inclusions in lava, near Mayen, Rhenish Prussia; Tombstone, Ariz.

Quetenite. $MgO.Fe_2O_3.3SO_3.13H_2O$. Massive, in indistinct crystals. Color reddish brown. From Quetena, Chile.

Zincaluminite. $2ZnSO_4.4Zn(OH)_2.6Al(OH)_3.5H_2O$. In minute hexagonal plates. Color white, bluish. From Laurion, Greece.

Johannite. A hydrous sulphate of uranium and copper. In druses or reniform masses of a green color. From Joachimstal, Bohemia.

Gilpinite. A hydrous sulphate of uranium and copper, $(Cu,Fe,Na_2)O.UO_3.SO_3.4H_2O$. Probably monoclinic. In minute lath-shaped crystals. Color pale greenish yellow to anary-yellow. H. = 2. G. > 3·3. Indices, 1·57–1·61. Infusible. Readily soluble in cids. From Gilpin Co., Col.

Uranopilite. Perhaps $CaU_8S_2O_{31}.25H_2O$. In velvety incrustations; yellow. From ohanngeorgenstadt, Germany.

Zippeite, voglianite, uraconite are uncertain uranium sulphates, from Joachimstal, Bohemia.

Minasragrite. An acid hydrous vanadyl sulphate $(V_2O_2)H_2(SO_4)_3.15H_2O$. Probably monoclinic. In granular aggregates, small mammillary masses, or in spherulites. Two cleavages. Color blue. Indices 1·51–1·54. Strongly pleochroic, deep blue to colorless. Easily fusible. Soluble in cold water. Found as an efflorescence on *patronite* from Minasragra, Peru.

Rhomboclase. A hydrated acid ferric sulphate, $Fe_2O_3.4SO_3.9H_2O$. In rhombic plates. Basal cleavage. Colorless. Occurs at Szomolnok, Hungary.

Tellurates; also Tellurites, Selenites

Montanite. $Bi_2O_3.TeO_3.2H_2O$. In earthy incrustations; yellowish to white. From Highland, Mon., with tetradymite.

Emmonsite. Probably a hydrated ferric tellurite. In thin yellow-green scales. From near Tombstone, Ariz.

Durdenite. Hydrous ferric tellurite, $Fe_2(TeO_3)_3.4H_2O$. In small mammillary forms; greenish yellow. Honduras.

Chalcomenite. Hydrous cupric selenite, $CuSeO_3.2H_2O$. In small blue monoclinic crystals. From the Cerro de Cacheuta, Argentina, with silver, copper selenides.

MOLYBDOMENITE is lead selenite and COBALTOMENITE probably cobalt selenite, from the same locality as chalcomenite.

Oxygen Salts

7. TUNGSTATES, MOLYBDATES

The monoclinic Wolframite Group and the tetragonal Scheelite Group are included here.

Wolframite Group

Wolframite	$(Fe,Mn)WO_4$	$a:b:c = 0{\cdot}8300:1:0{\cdot}8678$	$\beta = 89°\ 22'$
Hübnerite	$MnWO_4$	$0{\cdot}8362:1:0{\cdot}8668$	$89°\ 7\frac{1}{2}'$

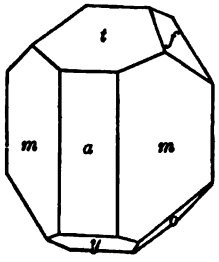
WOLFRAMITE.

Monoclinic. Axes $a : b : c = 0{\cdot}8300 : 1 : 0{\cdot}8678$; $\beta = 89°\ 22'$.

mm''', $110 \wedge 1\bar{1}0 = 79°\ 23'$. ay', $100 \wedge 10\bar{2} = 62°\ 54'$

at, $100 \wedge 102 = 61°\ 54'$. ff', $011 \wedge 011 = 81°\ 54'$.

1020



Twins: (1) tw. axis *c* with *a* (100) as comp.-face; (2) tw. pl. *k* (023), Fig. 449, p. 171. Crystals commonly tabular || *a* (100); also prismatic. Faces in prismatic zone vertically striated. Often bladed, lamellar, coarse divergent columnar, granular.

Cleavage: *b* (010) very perfect; also parting || *a* (100), and || *t* (102). Fracture uneven. Brittle. H. = 5–5·5. G. = 7·2–7·5. Luster submetallic. Color dark grayish or brownish black. Streak nearly black. Opaque. Sometimes weakly magnetic. $\beta = 1{\cdot}93$.

Comp. — Tungstate of iron and manganese $(Fe,Mn)WO_4$. Fe : Mn = chiefly 4 : 1 (FeO 18·9, MnO 4·7 p. c.) and 2 : 3 (FeO 9·5, MnO 14·0).

Pyr., etc. — Fuses B.B. easily (F. = 2·5–3) to a globule, which has a crystalline surface and is magnetic. With salt of phosphorus gives a clear reddish yellow glass while hot, which is paler on cooling; in R.F. becomes dark red; on charcoal with tin, if not too saturated, the bead assumes on cooling a green color, which continued treatment in R.F. changes to reddish yellow. With soda and niter on platinum foil fuses to a bluish green manganate. Decomposed by aqua regia with separation of tungstic acid as a yellow powder. Sufficiently decomposed by concentrated sulphuric acid, or even hydrochloric acid, to give a colorless solution, which, treated with metallic zinc, becomes intensely blue, but soon bleaches on dilution.

Obs. — Wolframite is often associated with tin ores; also in quartz, with native bismuth, scheelite, pyrite, galena, sphalerite, etc. In Bohemia in fine crystals at Schlackenwald, Zinnwald, Bohemia; in Germany at Schneeberg, Freiberg, Altenberg, Neudorf; at Nerchinsk, Siberia; Chanteloup, near Limoges, France; near Redruth and elsewhere in Cornwall with tin ores. From Sardinia; Greenland; Central Provinces, India. In South America, at Oruro in Bolivia. With tin stone at various points in New South Wales.

In the United States at Lane's mine, Monroe, Conn.; Flowe mine, Mecklenburg Co., N. C., with scheelite; in Mo., near Mine la Motte; Laurence Co., S. D.; Boulder Co., Col.; Ariz.

Use. — An ore of tungsten.

Hübnerite. Near wolframite, but containing 20 to 25 p. c. MnO. Usually in bladed forms, rarely in distinct terminated crystals. Color brownish red to hair-brown to nearly black. Streak yellowish brown, greenish gray. Often translucent. $\beta = 2·24$. Mammoth district, Nev.; Ouray County, Col., and near Silverton, San Juan Co.; Black Hills, S. D.; Dragoon, Ariz. Also in Peru, and in rhodochrosite at Adervielle in the Pyrenees.

Scheelite Group. Tetragonal-pyramidal

Scheelite	$CaWO_4$	pp' $(111 \wedge 1\bar{1}1) = 79° 55\frac{1}{2}'$	$c = 1·5360$
Cuprotungstite	$CuWO_4$		
Cuproscheelite	$(Ca,Cu)WO_4$		
Powellite	$Ca(Mo,W)O_4$	80° 1′	$c = 1·5445$
Stolzite	$PbWO_4$	80° 15′	$c = 1·5667$
Wulfenite	$PbMoO_4$	80° 22′	$c = 1·5771$

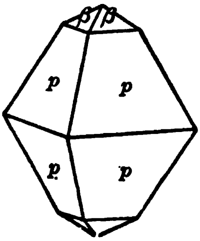
The Scheelite Group includes the tungstates and molybdates of calcium and lead; also copper. In crystallization they belong to the Pyramidal class of the Tetragonal System. Wulfenite is probably hemimorphic.

SCHEELITE.

Tetragonal-pyramidal. Axis $c = 1·5356$.

ee', $101 \wedge 011 = 72° 40\frac{1}{2}'$. pp', $111 \wedge 1\bar{1}1 = 79° 55\frac{1}{2}'$.
ce, $001 \wedge 101 = 56° 56'$. cp, $001 \wedge 111 = 65° 16\frac{1}{2}'$.

1021



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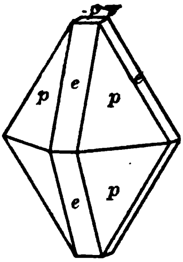

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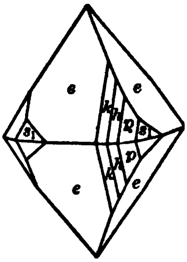

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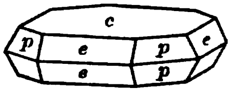

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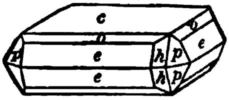


Forms: *o* (102), *e* (101), *β* (113), *p* (111), *k* (515), *h* (313), *s*,(131) Twins: (1) tw. pl. *a* (100), both contact- and penetration-twins (Fig. 416, p. 167). Habit octahedral, also tabular. Symmetry shown by faces *k*, *h*, *s* (Fig. 1023). Also reniform with columnar structure; massive granular.

Cleavage: *p* (111) most distinct; *e* (101) interrupted. Fracture uneven. Brittle. H. = 4·5–5. G. = 5·9–6·1. Luster vitreous, inclining to adamantine. Color white, yellowish white, pale yellow, brownish, greenish, reddish. Streak white. Transparent to translucent. Optically +. Indices: ω = 1·918. ϵ = 1·934.

Comp. — Calcium tungstate, $CaWO_4$ = Tungsten trioxide 80·6, lime 19·4 = 100.

Molybdenum is usually present (to 8 p. c.). Copper may replace calcium, see cuproscheelite.

Pyr., etc. — B.B. in the forceps fuses at 5 to a semi-transparent glass. Soluble with borax to a transparent glass, which afterward becomes opaque and crystalline. With salt of phosphorus forms a glass, colorless in outer flame, in inner green when hot, and fine blue when cold; varieties containing iron require to be treated on charcoal with tin before the blue color appears. In hydrochloric or nitric acid decomposed, leaving a yellow powder soluble in ammonia. The hydrochloric acid solution treated with tin and boiled assumes a blue color, later changing to brown.

Obs. — Scheelite is usually associated with crystalline rocks, and is commonly found in connection with cassiterite, topaz, fluorite, apatite, molybdenite, or wolframite, in quartz; also associated with gold. Thus at Schlackenwald and Zinnwald, Bohemia; Altenberg, Saxony; Riesengrund in the Riesengebirge, Germany; the Knappenwand in the Untersulzbachtal, Tyrol, Austria; Carrock Fells in Cumberland, England; Traversella in Piedmont, Italy; Meymac, Corrèze, France (containing Ta_2O_5); Sweden; Pitkäranta in Finland. In New South Wales, at Adelong, from a gold mine; New Zealand, massive; Mt. Ramsay, Tasmania, with cassiterite. From Sonora, Mexico.

In the United States, at Lane's Mine, Monroe, and at Trumbull, Conn.; Flowe mine, Mecklenburg Co., N. C.; the Mammoth mining district, Nev.; with gold at the Charity mine, Warren's, Idaho; Lake Co., Col.; Atolia mining field, Cal.; White Pine Co., Nev.; Dragoon, Ariz. In quartz veins in Risborough and Marlow, Beauce county, Quebec.

Use. — An ore of tungsten.

Cuprotungstite. Cupric tungstate, $CuWO_4$. From the copper mines of Llamuco, near Santiago, Chile. CUPROSCHEELITE, from the vicinity of La Paz, Lower California, is $(Ca,Cu)WO_4$, with 6·8 p. c. CuO; color green. From Montoro, Spain; from Yeoral, New South Wales.

Powellite. Calcium molybdate with calcium tungstate (10 p. c. WO_3), $Ca(Mo,W)O_4$. In minute yellow tetragonal pyramids. G. = 4·349. ω = 2·00. From western Idaho; Houghton Co., Mich.; from Llano Co., Texas, and Nye Co., Nev.

Stolzite. Lead tungstate, $PbWO_4$. In pyramidal tetragonal crystals. H. = 2·75–3. G. = 7·87–8·13. Color green to gray or brown. Optically −. ω = 2·269. Zinnwald, Bohemia; Sardinia; Minas Geraes, Brazil; Broken Hill, New South Wales. From Loudville, Mass.

Raspite. Has the same composition as stolzite, but is referred to the monoclinic system. In small tabular crystals. Color brownish yellow. Index, 2·60. From the Broken Hill mines, New South Wales; Minas Geraes, Brazil.

Chillagite. $3PbWO_4.PbMoO_4$. In tabular tetragonal crystals, apparently hemimorphic. Color yellow to brownish. H. = 3·5. G. = 7·5. From Chillagoe, Queensland.

WULFENITE.

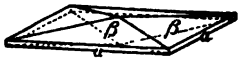
Tetragonal-pyramidal; hemimorphic. Axis c = 1·5771.

cu, 001 ∧ 102 = 38° 15′. *uu′*, 102 ∧ 012 = 51° 56′.
ce, 001 ∧ 101 = 57° 37′. *ee′*, 101 ∧ 011 = 73° 20′.
cn, 001 ∧ 111 = 65° 51′. *nn′*, 111 ∧ $\bar{1}$11 = 80° 22′.

Crystals commonly square tabular, sometimes extremely thin; less frequently octahedral; also prismatic. Hemimorphism sometimes distinct. Also granularly massive, coarse or fine, firmly cohesive.

Cleavage: *n* (111) very smooth; *c* (001), *s* (113) less distinct. Fracture subconchoidal. Brittle. H. = 2·75–3. G. = 6·7–7·0. Luster resinous or adamantine. Color wax- to orange-yellow, siskin- and olive-green, yellowish gray, grayish white to nearly colorless, brown; also orange to bright red. Streak white. Subtransparent to subtranslucent. Optically negative. Indices: $\omega_{\gamma} = 2·402$, $\epsilon_{\gamma} = 2·304$.

1026



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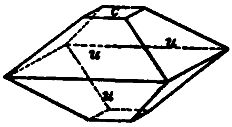

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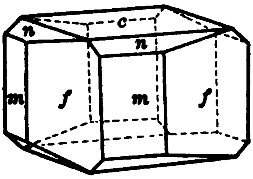

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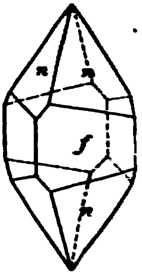

Comp. — Lead molybdate, $PbMoO_4$ = Molybdenum trioxide 39·3, lead oxide 60·7 = 100. Calcium sometimes replaces the lead.

Pyr., etc. — B.B. decrepitates and fuses below 2. With salt of phosphorus in O.F. gives a yellowish green glass, which in R.F. becomes dark green. With soda on charcoal yields metallic lead. Decomposed on evaporation with hydrochloric acid, with the formation of lead chloride and molybdic oxide; on moistening the residue with water and adding metallic zinc, it gives an intense blue color, which does not fade on dilution of the liquid.

Obs. — Occurs in veins with other ores of lead. At Bleiberg, Carinthia; Rezbánya, Hungary; Přibram, Austria; Moldawa in the Banat, Hungary; Annaberg, Schneeberg, Germany; Sardinia; Broken Hill, New South Wales.

In the United States, sparingly at the Southampton lead mine, and at Quincy, Mass., and near Sing Sing, N. Y.; near Phenixville, Pa.; at the Comstock lode and at Eureka in Nev.; in large thin orange-yellow tables at the Tecomah mine, Utah. In N. M., pale yellow crystals in the Organ Mts. In Ariz., large deep red crystals at the Hamburg and other mines, Yuma Co., often with red vanadinite; also at the Castle Dome district, 30 miles distant; at the Mammoth gold mine near Oracle, Pinal Co., with vanadinite and descloizite.

Named after the Austrian mineralogist Wülfen (1728–1805).

Use. — An ore of molybdenum.

Reinite. Ferrous tungstate, $FeWO_4$. In blackish brown tetragonal pyramids, perhaps pseudomorphous. H. = 4. G. = 6·64. Kimbosan, Japan.

Koechlinite. A molybdate of bismuth, $Bi_2O_3.MoO_3$. Orthorhombic. In minute tabular crystals. Cleavage, *a* (100). Color, greenish yellow. Index, 2·55. Easily fusible. From Schneeberg, Saxony, Germany.

Ferritungstite. $Fe_2O_3.WO_3.6H_2O$. In microscopic hexagonal plates. Color pale yellow to brownish yellow. Decomposed by acids leaving yellow tungstic oxide. Product of oxidation of Wolframite from Germania Tungsten mine. Deer Trail district, Wash.

VII. SALTS OF ORGANIC ACIDS

Oxalates, Mellates

Whewellite. Calcium oxalate, $CaC_2O_4.H_2O$. In small colorless monoclinic crystals. Optically +. β = 1·555. From Saxony, with coal; also from Bohemia and Alsace.

Oxammite. Ammonium oxalate, $(NH_4)_2C_2O_4.2H_2O$. From the guano of the Guañape Islands, Peru.

Humboldtine. Hydrous ferrous oxalate, $FeC_2O_4.2H_2O$. Orthorhombic. Color yellow. $\beta = 1{\cdot}561$. From near Bilin, Bohemia; Capo d'Arco, Elba.

Mellite. Hydrous aluminium mellate, $Al_2C_{12}O_{12}.18H_2O$. In square tetragonal pyramids; also massive, granular. G. = 1·55–1·65. Color honey-yellow. Optically –. $\omega = 1{\cdot}539$. Occurs in brown coal in Thuringia, Bohemia, etc.

VIII. HYDROCARBON COMPOUNDS

The Hydrocarbon compounds in general, with few exceptions, are *not homogeneous substances*, but mixtures, which by the action of solvents or by fractional distillation may be separated into two or more component parts. They are hence not definite mineral species and do not strictly belong to pure Mineralogy, rather, with the recent gums and resins, to Chemistry or, so far as they are of practical value, to Economic Geology. In the following pages they are treated for the most part with great brevity.

1. Simple Hydrocarbons. Chiefly members of the Paraffin Series C_nH_{2n+2}.

SCHEERERITE. In whitish monoclinic crystals. Perhaps a polymer of marsh-gas (CH_4). Found in brown coal at Uznach, Switzerland.

HATCHETTITE. Mountain Tallow. In thin plates, or massive. Like soft wax. Color yellowish. Indices, 1·47–1·50. Ratio of C to H = nearly 1 : 1. From the Coal-measures near Merthyr-Tydvil in Glamorganshire, England; from Galicia.

PARAFFIN. A native crystallized paraffin has been described as occurring in cavities in basaltic lava near Paterno, Sicily. Indices, 1·49–1·52.

OZOCERITE. Mineral wax in part. Like wax or spermaceti in appearance and consistency. Colorless to white when pure; often leek-green, yellowish, brownish yellow, brown. Indices, 1·51–1·54. Essentially a paraffin, and consisting chiefly of one of the higher members of the series. Occurs in beds of coal, or associated bituminous deposits, as at Slanik, Moldavia; Roumania; Boryslaw in the Carpathians. Also occurs in southern Utah on a large scale.

Zietrisikite, *Chrismatite*, *Urpethite* are near ozocerite.

FICHTELITE. In white monoclinic tabular crystals. Perhaps C_5H_8. Occurs in thin layers of pine wood from peat-beds, near Redwitz, in the Fichtelgebirge, Bavaria; from Borkovic, Bohemia. *Hartite* has a similar occurrence.

NAPALITE. A yellow bituminous substance of the consistency of shoemaker's wax. C_3H_4. From the Phœnix mercury mine in Pope Valley, Napa county, Cal.

2. Oxygenated Hydrocarbons

AMBER. In irregular masses, with conchoidal fracture. H. = 2–2·5. G. = 1·096. Luster resinous. Color yellow, sometimes reddish, brownish, and whitish, often clouded, sometimes fluorescent. Transparent to translucent. Heated to 150° begins to soften, and finally melts at 250°–300°. Ratio for C : H : O = 40 : 64 : 4.

Part of the so-called amber is separated mineralogically as *succinite* (yielding succinic acid). Other related fossil resins from many other regions (e.g., the Atlantic coast of the United States) have been noted. Some of them have been called *retinite*, *gedanite*, *glessite*, *rumänite*, *simetite*, *krantzite*, *chemawinite*, *delatynite*, etc.

Amber occurs abundantly on the Prussian coast of the Baltic from Dantzig to Memel; also on the coasts of Denmark, Sweden, and the Russian Baltic provinces. It is mined extensively, and is also found on the shores cast up by the waves after a heavy storm. Amber and the similar fossil resins are of vegetable origin, altered by fossilization; this is inferred both from its native situation with coal, or fossil wood, and from the occurrence of insects incased in it. Amber was early known to the ancients, and called ἤλεκτρον, *electrum*, whence, on account of its electrical susceptibilities, has been derived the word *electricity*.

COPALITE, or Highgate resin, is from the London blue clay. It is like the resin copal in hardness, color, luster, transparency, and difficult solubility in alcohol. Color clear pale yellow to dirty gray and dirty brown. Emits a resinous aromatic odor when broken.

The following are oxygenated hydrocarbons occurring with coal and peat deposits, etc.:

BATHVILLITE. Occurs in dull, brown, porous lumps in the torbanite or Boghead coal (of the Carboniferous formation) adjoining the lands of Torbane Hill, Bathville, Scotland. It may be an altered resin, or else material which has filtrated into the cavity from the surrounding torbanite.

TASMANITE. In minute reddish brown scales disseminated through a laminated shale; average diameter of scales about 0·03 in. Not dissolved at all by alcohol, ether, benzene. turpentine, or carbon disulphide, even when heated. Remarkable as yielding 5·3 p. c, sulphur. From the river Mersey, north side of Tasmania; the rock is called *combustible shale*.

DYSODILE. In very thin folia, flexible, slightly elastic; yellow or greenish gray. Analysis gave 2·3 p. c. sulphur and 1·7 p. c. nitrogen. From lignite deposits at Melili, Sicily, and elsewhere.

GEOCERITE. A white, wax-like substance, separated from the brown coal of Gesterwitz, near Weissenfels. *Geomyricite* and *geocerellite* are other products from the same source.

LEUCOPETRITE. Also from the Gesterwitz brown coal. Between a resin and wax in physical characters.

PYRORETINITE. From brown coal near Aussig, Bohemia.

DOPPLERITE. In elastic or partly jelly-like masses; brownish black. An acid substance, or mixture of different acids, related to humic acid. Ratio for C, H, O, nearly 10 : 12 : 5. From peat beds near Aussee in Styria; Fichtelgebirge, Bavaria.

IDRIALITE. Occurs with the cinnabar of Idria. In the pure state white and crystalline in structure. In nature found only impure, being mixed with cinnabar, clay, and some pyrite and gypsum in a brownish black earthy material, called, from its combustibility and the presence of mercury, *inflammable cinnabar*.

POSEPNYTE. Occurs in hard, brittle plates or nodules, light green in color. From the Great Western mercury mine, Lake Co., Cal. See also napalite, p. 645.

FLAGSTAFFITE. $C_{12}H_{24}O_3$. Orthorhombic. In minute prisms. Colorless. $n = 1·51$. G. = 1·092. Found in cracks of buried tree trunks, near Flagstaff, Ariz.

The following are still more complex native hydrocarbon compounds of great importance from an economic standpoint.

Petroleum. NAPHTHA; PETROLEUM. Mineral oil. Kerosene.

PITTASPHALT: Maltha. Mineral Tar.

Liquids or oils, in the crude state of disagreeable odor; varying widely in color, from colorless to dark yellow or brown and nearly black, the greenish brown color the most common; also in consistency from thin flowing kinds to those that are thick and viscous; and in specific gravity from 0·6 to 0·9. Petroleum, proper, passes by insensible gradations into *pittasphalt* or *maltha* (viscid bitumen); and the latter as insensibly into *asphalt* or solid bitumen.

Chemically, petroleum consists for the most part of members of the paraffin series, C_nH_{2n+2}, varying from marsh gas, CH_4, to the solid forms. The olefines, C_nH_{2n}, are also present in smaller amount. This is especially true of the American oils. Those of the Caucasus have a higher density, the volatile constituents are less prominent, they distill at about 150° and contain the benzenes, C_nH_{2n-6}, in considerable amount. There are present also members of the series C_nH_{2n-8}. The German petroleum is intermediate between the American and the Caucasian. The Canadian petroleum is especially rich in the solid paraffins.

Petroleum occurs in rocks or deposits of nearly all geological ages, from the Lower Silurian to the present epoch. It is associated most abundantly with argillaceous shales, sands, and sandstones, but is found also permeating limestones, giving them a bituminous odor, and rendering them sometimes a considerable source of oil. From these oleiferous shales, sands and limestones the oil often exudes, and appears floating on the streams or lakes of the region, or rises in oil springs. It also exists collected in subterranean cavities in certain rocks, whence it issues in jets or fountains whenever an outlet is made by boring. The oil which fills the cavities has ordinarily been derived from the subjacent rocks; for the strata in which the cavities exist are frequently barren sandstones. The conditions required for the production of such subterranean accumulations would be therefore a bituminous oil-bearing or else oil-producing stratum at a greater or less depth below; cavities to receive the oil; an overlying stratum of close-grained shale or limestone, not allowing of the easy escape of the naphtha vapors.

The important petroleum districts in the United States are: (1) The Appalachian including fields in N. Y., Pa., Ohio, W. Va., Ky., Tenn., (2) The Ohio-Indiana, (3) Illinois, (4) Kansas-Oklahoma, (5) Louisiana-Texas, (6) California, (7) Wyoming. In Canada oil chiefly produced in Ontario. Important fields in Mexico from Tampico to Tuxpam. The chief foreign districts are in the Baku region, Russia, in Galicia and Roumania, also in Borneo.

Asphaltum. Mineral Pitch. Asphalt.

Asphaltum, or mineral pitch, is a mixture of different hydrocarbons, part of which are oxygenated. Its ordinary characters are as follows: Amorphous. G. = 1–1·8; sometimes higher from impurities. Luster like that of black pitch. Color brownish black and black. Odor bituminous. Melts ordinarily at 90° to 100°, and burns with a bright flame. Soluble mostly or wholly in oil of turpentine, and partly or wholly in ether; commonly partly in alcohol. The more solid kinds graduate into the pittasphalts or mineral tar, and through these there is a gradation to petroleum. The fluid kinds change into the solid by the loss of a vaporizable portion on exposure, and also by a process of oxidation, which consists first in a loss of hydrogen, and finally in the oxygenation of a portion of the mass. The action of heat, alcohol, ether, naphtha and oil of turpentine, as well as direct analyses, show that the so-called asphaltum from different localities is very various in composition.

Asphaltum belongs to rocks of no particular age. The most abundant deposits are superficial. But these are generally, if not always, connected with rock deposits containing some kind of bituminous material or vegetable remains. Some of the noted localities of asphaltum are the region of the Dead Sea, or Lake Asphaltites, whence the most of the asphaltum of ancient writers; a lake on Trinidad, 1½ m. in circuit, which is hot at the center, but is solid and cold toward the shores, and has its borders over a breadth of ½ m. covered with the hardened pitch with trees flourishing over it; at various places in South America; in California, near the coast of St. Barbara; also in smaller quantities, elsewhere.

ELATERITE. Elastic Bitumen. Mineral Caoutchouc. Soft, elastic, sometimes much like india-rubber; occasionally hard and brittle. Color usually dark brown. Found at Castleton in Derbyshire, and elsewhere.

ALBERTITE. Differs from ordinary asphaltum in being only partially soluble in oil of turpentine, and in its very imperfect fusion when heated. H. = 1–2. G. = 1·097. Luster brilliant, pitch-like; color jet-black. Occurs filling an irregular fissure in rocks of the Lower Carboniferous in Nova Scotia. *Impsonite* from Impson valley, Indian Territory, is like albertite except that it is almost insoluble in turpentine.

GRAHAMITE. Resembles albertite in its pitch-black, lustrous appearance. H. = 2. G. = 1·145. Soluble mostly in oil of turpentine; partly in ether, naphtha or benzene; not at all in alcohol; wholly in chloroform and carbon disulphide. Melts only imperfectly, and with a decomposition of the surface. Occurs in W. Va., about 20 m. S. of Parkersburg, filling a fissure in a Carboniferous sandstone; from Kunda, Esthonia, Russia.

GILSONITE, also called *Uintahite* or Uintaite. A variety of asphalt from near Ft. Duchesne, Utah, which has found many applications in the arts. Occurs in masses several inches in diameter, with conchoidal fracture; very brittle. H. = 2–2·5; G. = 1·065–1·070. Color black, brilliant and lustrous; streak and powder a rich brown. Fuses easily in the flame of a candle and burns with a brilliant flame, much like sealing-wax. Named after Mr. S. H. Gilson of Salt Lake City.

NIGRITE is a variety of asphaltum from Utah.

Mineral Coal. Compact massive, without crystalline structure or cleavage; sometimes breaking with a degree of regularity, but from a jointed rather than a cleavage structure. Sometimes laminated; often faintly and delicately banded, successive layers differing slightly in luster. Fracture conchoidal to uneven. Brittle; rarely somewhat sectile. H. = 0·5–2·5. G. = 1–1·80. Luster dull to brilliant, and either earthy, resinous or submetallic. Color black, grayish black, brownish black, and occasionally iridescent; also sometimes dark brown. Opaque. Infusible to subfusible; but often becoming a soft, pliant or paste-like mass when heated. On distillation most kinds afford more or less of oily and tarry substances, which are mixtures of hydrocarbons and paraffin.

The varieties recognized depend partly (1) on the amount of the volatile ingredients afforded on destructive distillation; or (2) on the nature of these volatile compounds, for ingredients of similar composition may differ widely in volatility, etc.; (3) on structure, luster and other physical characters.

Coal is in general the result of the gradual change which has taken place in geological history in organic deposits, chiefly vegetable, and its form and composition depend upon the extent to which this change has gone on. Thus it passes from forms which still retain the original structure of the wood (peat, lignite) and through those with less of volatile or bituminous matter to anthracite and further to kinds which approach graphite.

1. ANTHRACITE. H. = 2–2·5. G. = 1·32–1·7. Luster bright, often submetallic, iron-black, and frequently iridescent. Fracture conchoidal. Volatile matter after drying 3–6 p. c. Burns with a feeble flame of a pale color. The anthracites of Pennsylvania contain ordinarily 85–93 per cent of carbon; those of South Wales, 88–95; of France, 80–83; of Saxony, 81; of southern Russia, sometimes 94 per cent. Anthracite graduates through semi-anthracite into bituminous coal, becoming less hard and containing more volatile matter; and an intermediate variety is called *free-burning* anthracite.

2. BITUMINOUS COAL. Burns in the fire with a yellow, smoky flame, and gives out on distillation hydrocarbon oils or tar; hence the name *bituminous*. The *ordinary* bituminous coals contain from 5–15 p. c. (rarely 16 or 17) of oxygen (ash excluded); while the so-called *brown coal* or *lignite* contains from 20–36 p. c., after the expulsion, at 100°, of 15–36 p. c. of water. The amount of hydrogen in each is from 4–7 p. c. Both have usually a bright, pitchy, greasy luster, a firm compact texture, are rather fragile compared with anthracite, and have G. = 1·14–1·40. The *brown* coals have often a brownish black color, whence the name, and more oxygen, but in these respects and others they shade into ordinary bituminous coals. The ordinary bituminous coal of Pennsylvania has G. = 1·26–1·37; of Newcastle, England, 1·27; of Scotland, 1·27–1·32; of France, 1·2–1·33; of Belgium, 1·27–1·3. The most prominent kinds are the following:

(*a*) *Caking* or *Coking Coal*. A bituminous coal which softens and becomes pasty or semi-viscid in the fire. This softening takes place at the temperature of incipient decomposition, and is attended with the escape of bubbles of gas. On increasing the heat, the volatile products which result from the ultimate decomposition of the softened mass are driven off, and a coherent, grayish black, cellular or fritted mass (*coke*) is left. Amount of coke left (or part not volatile) varies from 50–85 p. c.

(*b*) *Non-Caking Coal*. Like the preceding in all external characters, and often in ultimate composition; but burning freely without softening or any appearance of incipient fusion. There are all gradations between caking and non-caking bituminous coals.

(*c*) *Cannel Coal* (Parrot Coal). A variety of bituminous coal, and often caking; but differing from the preceding in texture, and to some extent in composition, as shown by its products on distillation. It is compact, with little or no luster, and without any appearance of a banded structure; and it breaks with a conchoidal fracture and smooth surface; color dull black or grayish black. On distillation it affords, after drying, 40 to 66 p. c. of volatile matter, and the material volatilized includes a large proportion of burning and lubricating oils, much larger than the above kinds of bituminous coal; whence it is extensively used for the manufacture of such oils. It graduates into oil-producing coaly shales, the more compact of which it much resembles. *Torbanite* is a variety of cannel coal of a dark brown color, from Torbane Hill, near Bathgate, Scotland; also called *Boghead Cannel*.

(*d*) *Brown Coal* (Lignite). The prominent characteristics of brown coal have already been mentioned. They are non-caking, but afford a large proportion of volatile matter; sometimes pitch-black, but often rather dull and brownish black. G. = 1·15–1·3. Brown coal is often called *lignite*. But this term is sometimes restricted to masses of coal which still retain the form of the original wood. *Jet* is a black variety of brown coal, compact in texture, and taking a good polish, whence its use in jewelry.

Coal occurs in beds, interstratified with shales, sandstones, and conglomerates, and sometimes limestones, forming distinct layers, which vary from a fraction of an inch to 30 feet or more in thickness. In the United States, the anthracites occur east of the Alleghany range, in rocks that have undergone great contortions and fracturings, while the bituminous coals are found extensively in many States farther west, in rocks that have been less disturbed; and this fact and other observations have led geologists to the view that the anthracites have lost their bitumen by the action of heat. The *origin* of coal is mainly vegetable, though animal life has contributed somewhat to the result. The beds were once beds of vegetation, analogous, in most respects, in mode of formation to the peat beds of modern times, yet in mode of burial often of a very different character. This vegetable origin is proved not only by the occurrence of the leaves, stems and logs of plants in the coal, but also by the presence throughout its texture, in many cases, of the forms of the original fibres; also by the direct observation that peat is a transition state between unaltered vegetable débris and brown coal, being sometimes found passing completely into true brown coal. *Peat* differs from true coal in want of homogeneity, it visibly containing vegetable fibers only partially altered; and wherever changed to a fine-textured homogeneous material, even though hardly consolidated, it may be true brown coal.

For an account of the chief coal fields, as also of the geological relations of the different coal deposits, reference is made to works on Economic Geology.

APPENDIX A.

ON THE DRAWING OF CRYSTAL FIGURES

In the representation of crystals by figures it is customary to draw their edges as if they were projected upon some definite plane. Two sorts of projection are used; the *orthographic* in which the lines of projection fall at right angles and the *clinographic* where they fall at oblique angles upon the plane of projection. The second of these projections is the more important, and must be treated here in some detail. Two points are to be noted in regard to it. In the first place, in the drawings of crystals the point of view is supposed to be at an infinite distance, and it follows from this that all lines which are parallel on the crystal appear *parallel* in the drawing.

In the second place, in all ordinary cases, it is the complete ideal crystal which is represented, that is, the crystal with its full geometrical symmetry as explained on pp. 10 to 13 (cf. note on p. 13).

In general, drawings of crystals are made, either by constructing the figure upon a projection of its crystal axes, using the intercepts of the different faces upon the axes in order to determine the directions of the edges or by constructing the figure from the gnomonic (or stereographic) projection of the crystal forms. Both of these methods have their advantages and disadvantages. By drawing the crystal figure by the aid of a projection of its crystal axes the symmetry of the crystal and the relations of its faces to the axes are emphasized. In many cases, however, drawing from a projection of the poles of the crystal faces is simpler and takes less time. The student should be able to use both methods and consequently both are described below.

DRAWING OF CRYSTALS UPON PROJECTIONS OF THEIR CRYSTAL AXES

Projection of the Axes

The projection of the particular axes required is obviously the first step in the process. These axes can be most easily obtained by making use of the Penfield Axial Protractor, illustrated in Fig. 1030.* The customary directions of the axes for the isometric, tetragonal, orthorhombic and hexagonal systems are given on the protractor and it is a simple matter, as explained below, to determine the directions of the inclined axes of the monoclinic and triclinic systems. Penfield drawing charts giving the projection of the isometric axes, which are easily modified for the tetragonal and orthorhombic systems, and of the hexagonal axes, (see Figs. 1031, 1032) are also quite convenient.

Isometric System. — The following explanation of the making of the projection of the isometric axes has been taken largely from Penfield's description.†

Figure 1033 will make clear the principles upon which the projection of the isometric axes are based. Figure 1033A is an orthographic projection (a *plan*, as seen from above) of a cube in two positions, one, *a b c d*, in what may be called normal position, the other, *A B C D*, after a revolution of 18° 26′ to the left about its vertical axis. The broken-dashed lines throughout represent the axes. Figure 1033B is likewise an orthographic projection of a cube in the position *A B C D* of A, when viewed from in front, the eye or point of vision being on a level with the crystal. In the position chosen, the apparent width of the side face *B C B′ C′* is one-third that of the front face *A B A′ B′*, this being dependent upon the angle of revolution 18° 26′, the tangent of which is equal to ⅓. To construct the angle 18° 26′, draw a perpendicular at any point on the horizontal line, *X − Y*, figure 1033A as at *o*, make *op* equal one-third *Oo*, and join *O* and *p*. The next step in the construction is to change from orthographic to clinographic projection. In order to give crystal figures the appearance of solidity it is supposed that the eye or point

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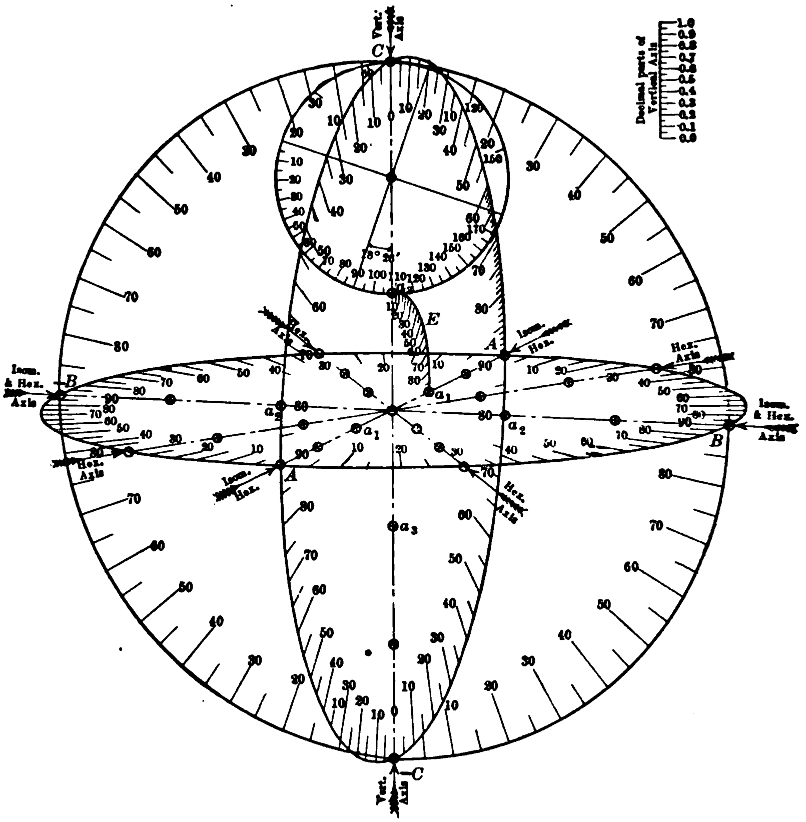
* The various Penfield crystal drawing apparatus may be obtained from the Mineralogical Laboratory of the Sheffield Scientific School of Yale University, New Haven, Conn.

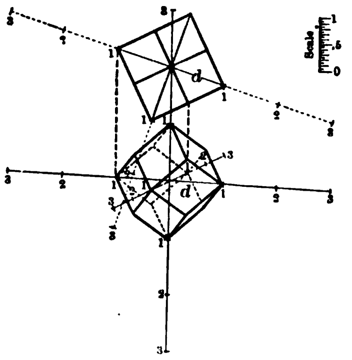
† On Crystal Drawing; Am. J. Sc., **19**, 39, 1905.

1030

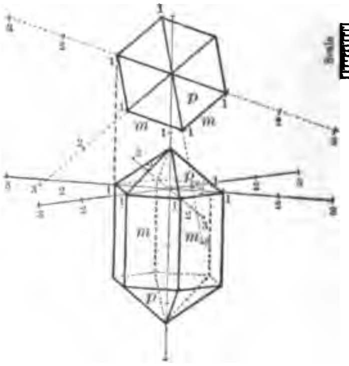


Protractor for plotting crystallographic axes; one-third natural size (after Penfield)

1031

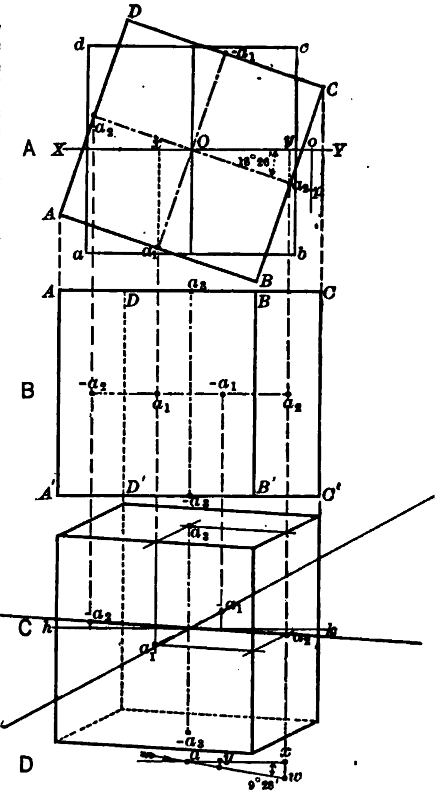


1032



Scheme of the engraved axes of the isometric and hexagonal systems, one-sixth natural size (after Penfield) of vision is raised, so that one looks down at an angle upon the crystal; thus, in the case under consideration, figure 1033C, the top face of the cube comes into view. The position of the crystal, however, is not changed, and the plane upon which the projection is made remains vertical. From A it may be seen that the positive ends of the axes a_1 and a_2 are forward of the line XY, the distances a_1x and $a_2\,y$ being as 3 : 1. In B it must be imagined, and by the aid of a model it may easily be seen, that the extremities of these same axes are to the front of an imaginary vertical plane (the projection of XY above) passing through the center of the crystal, the distance being the same as $a_1\,x$ and $a_2\,y$ of the plan. In D the distance ax is drawn the same length as a_1x of the plan, and the amount to which it is supposed that the eye is raised, indicated by the arrow, is such that a, instead of being projected horizontally to x, is projected at an inclination of 9° 28′ from the horizontal to w, the distance xw being one-sixth of ax; hence the angle 9° 28′ is such that its tangent is $\frac{1}{6}$. Looking down upon a solid at an angle, and still making the projection on a vertical plane, may be designated as *clinographic projection;* accordingly, to plot the axes of a cube in clinographic projection in conformity with figures A, B and D draw the horizontal construction line hk, figure C, and cross it by four perpendiculars in vertical alignment with the points a_1, $-a_1$ and a_2, $-a_2$ of figures A and B. Then determine the extremities of the first, a_1, $-a_1$ axis by laying off distances equal to xw of figure D, or one-sixth $a_1\,x$ of figure A, locating them below and above the horizontal line hk. The line a_1, $-a_1$ is thus the projection of the first, or front-to-back axis. In like manner determine the extremities of the second axis, a_2, $-a_2$, by laying off distances equal to one-third xw of figure D, or one-sixth a_2y of figure A, plotted below and above the line hk. The line a_2, $-a_2$ is thus the projection of the second, or right-to-left axis. It is important to keep in mind that in clinographic projection there is no foreshortening of vertical distances. In figure C the axis a_2, $-a_2$ is somewhat, and a_1, $-a_1$ much foreshortened, yet both represent axes of the same length as the vertical, a_3, $-a_3$.

1033

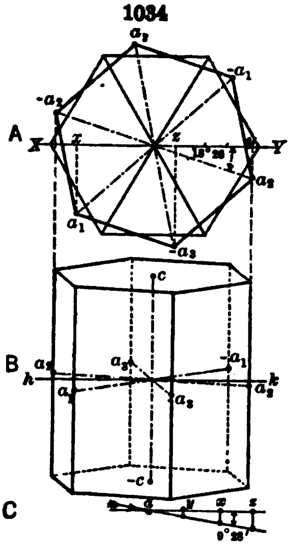


Development of the axes of the isometric system in orthographic and clinographic projection (after Penfield)

It is wholly a matter of choice that the angle of revolution shown in figure 1033A is 18° 26′, and that the eye is raised so as to look down upon a crystal at an angle of 9° 28′ from the horizontal, as indicated by figure 1033D. Also it is evident that these angles may be varied to suit any special requirement. As a matter of fact, however, the angles 18° 26′ and 9° 28′ have been well chosen and are established by long usage, and practically all the figures in clinographic projection, found in modern treatises on crystallography and mineralogy, have been drawn in accordance with them.

Tetragonal and Orthorhombic Systems. — The projection of tetragonal and orthorhombic axes can be easily obtained from the isometric axes by modifying the lengths of the various axes to conform to the axial ratio of the desired crystal. For instance with zircon the vertical axis has a relative length of $c = 0.64$ in respect to the equal lengths of the horizontal axes. By taking 0.64 of the unit length of the vertical axis of the isometric projection the crystal axes for a zircon figure are obtained. The Penfield axial charts all give decimal parts of the unit length of the isometric vertical axis, so that any proportion of this length can be found at once. In the orthorhombic system the lengths of both the a and c axes must be modified. The desired point upon the c axis can be obtained as described above. In the case of the a axis the required point can be found by some simple method of construction. If, as is the case in the Penfield charts, a plan of the unforeshortened horizontal axes is given in a top view, the desired length can be laid off directly upon the *a* axis in this orthographic projection by means of the decimal scale and then projected vertically down upon its clinographic projection. Or the proper distance can be laid off on the vertical axis and then by means of a line drawn from this point parallel to a line joining the extremities of the *c* and *a* axes of the isometric projection the proper proportional part of the *a* axis can be determined by intersection.

1034



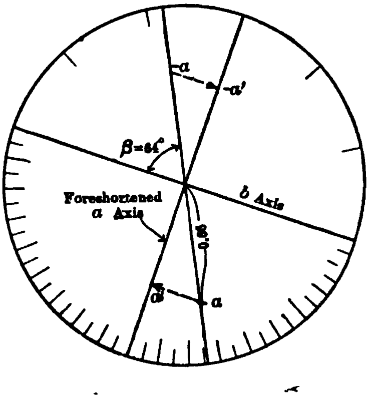
Development of the axes of the hexagonal system in orthographic and clinographic projection (after Penfield)

Hexagonal System. — For projecting the hexagonal axes exactly the same principles may be made use of as were employed in the construction of the isometric axes. Figure 1034A is an orthographic projection, a *plan*, of a hexagonal prism in two positions, one of them, a_1, a_2, etc., after a revolution of 18° 26′ from what may be called normal position. In figure 1034B the extremities of the horizontal axes of A have been projected down upon the horizontal construction line *hk*, and a_1, a_2 and $-a_3$ which are forward of the line *XY* in A are located below the line *hk* in the clinographic projection, the distances from *hk* being one-sixth of a_1x, a_2y and $-a_3z$ of A. Figure 1034C is a scheme for getting the distances which the extremities of the axes are dropped. The vertical axis in 1034B has been given the same length as the axes of the plan.

Monoclinic System. — In the case of the monoclinic axes the inclination and length of the *a* axis must be determined in each case. The axial chart, Fig. 1030, can be most conveniently used for this purpose. The ellipse in the figure, lettered A, C, – A, – C gives the trace of the ends of the *a* and *c* axes as they are revolved in the A — C plane. To find, therefore, the inclination of the *a* axis it is only necessary to lay off the angle β by means of the graduation given on this ellipse. The unit length of the *a* axis may be determined in various ways. The plan of the axes given at the top of the chart may be used for this purpose. Fig. 1035 will illustrate the method of procedure as applied in the case of orthoclase, where $\beta = 64°$ and $a = 0.66$. The foreshortened length of the *a* axis is determined as indicated and then this length can be projected vertically downward upon the inclined *a* axis, the direction of which has been previously determined as described above.

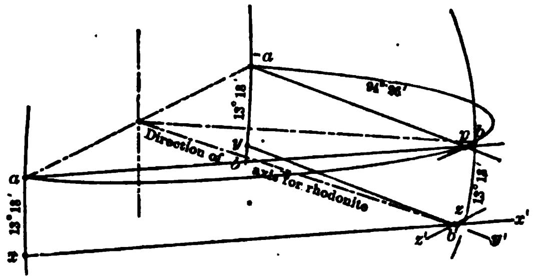
Triclinic System. — In the construction of triclinic axes the inclination of the *a* axis and its length are determined in exactly the same manner as described in the preceding paragraph in the case of the monoclinic system. The direction of the *b* axis is determined as follows. The vertical plane of the *b* and *c* axes is revolved about the *c* axis through such an angle as will conform to the angle between the pinacoids 100 and 010. Care must be taken to note whether this plane is to be revolved toward the front or toward the back. If the angle between the normals to 100 and 010 is greater than 90° the right hand end of this plane is to be revolved toward the front. Figure 1036, which is a simplified portion of the axial chart, shows the necessary construction in order to obtain the direction of the *b* axis in the case of rhodonite in which 100 ∧ 010 = 94° 26′ and $\alpha = 103° 18'$. The plane of the *b–c* axes will pass through the point *p* which is 94° 26′ from *–a*. To locate the point *b′*, which is the point where the *b* axis would emerge from the sphere, draw through the point *p* two or more chords from points where the vertical ellipses of the chart cross the horizontal ellipse, as lines *a–p*. *–a–p*. *b–p*, in figure 1036. Then from points on these same vertical ellipses which are 13° 18′ below the horizontal plane draw chords parallel to the first series as *x–x′*, *y–y′*, *z–z′*. The point where these three chords meet determines the position of *b′* and a line from this point drawn through the center of the

1035



art determines the direction of the b axis, since it lies in the proper vertical plane and akes the angle α, 103° 18′, with the c axis. The foreshortened length of the b axis can e determined by the use of the orthographic projection of the a and b axes at the top of he chart in exactly the same manner as described under the monoclinic system and the oint thus determined may be projected vertically downward upon the line of the b axis f the clinographic projection as lready determined. It must be emembered, however, that the osition of the b axis in the orthographic projection must conform to the position of the plane of the b and c axes or in the case of rhodonite have its right hand end at an angle of 94° 26′ with the negative end of the projection of the a axis.

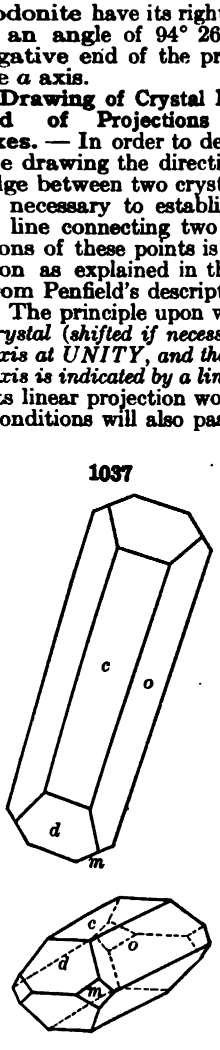
1036



Drawing of Crystal Figures by Aid of Projections of their Axes. — In order to determine in the drawing the direction of any edge between two crystal faces it is necessary to establish two points, both of which shall be common to these two faces. A line connecting two such points will obviously have the desired direction. The positions of these points is commonly established by use of the linear or Quendstedt projection as explained in the following paragraphs, which have been taken almost verbatim from Penfield's description of the process.

The principle upon which the linear projection is based is very simple: *Every face of a crystal (shifted if necessary, but without change of direction) is made to intersect the vertical axis at UNITY, and then its intersection with the horizontal plane, or the plane of the a and b axis is indicated by a line.* For instance if a given face has the indices 111 it is clear that its linear projection would be a line passing through 1a and 1b, since the face under these conditions will also pass through 1c. If, however, the indices of the face are 112 it will only pass through 1/2 c when it passes through 1a and 1b. In order to fulfill, therefore, the requirements of the linear projection that the plane should pass through 1c the indices must be multiplied by two and then under these conditions the line in which the plane intercepts the horizontal plane, or in other words the linear projection of the face, will pass through 2a and 2b. In the case of a prism face with the indices 110, its linear projection will be a line having the same direction as a line joining 1a and 1b but passing through the point of intersection of these axes, since a vertical plane such as a prism can only pass through 1c when it also includes the c axis and so must have its linear projection pass through the point of intersection of the three axes.

1037



When it is desired to find the direction of an edge made by the meeting of any two faces, the lines representing the linear projection of the faces are first drawn, and the point where they intersect is noted. Thus a point common to both faces is determined, which is located in the plane of the a and b axes. A second point common to the two faces is *unity* on the vertical axis, and a line from this point to where the lines of the linear projection intersect gives the desired direction.

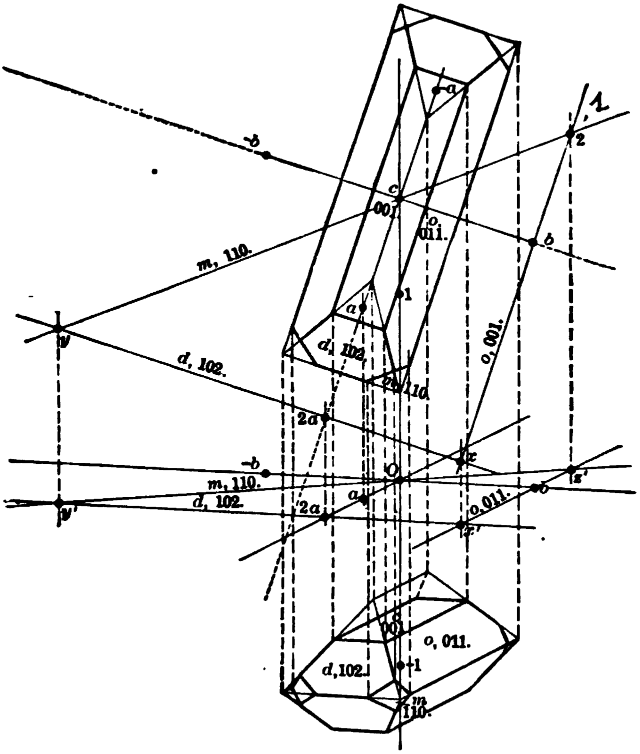
A simple illustration, chosen from the orthorhombic system, will serve to show how the linear projection may be employed in drawing. The example is a combination of barite, such as is shown in figure 1037. The axial ratio of barite is as follows:

$$a : b : c = 0{\cdot}8152 : 1 : 1{\cdot}3136$$

The forms shown in the figure and the symbols are, base c (001), prism m (110), brachydome o (011) and macrodome d (102).

Figure 1038 represents the details of construction of the orthographic and clinographic projections shown in figure 1037. On the orthographic axes the axial lengths a and b are located, the vertical axis c being foreshortened to a point at the center. On the clinographic axes, centered at *O*, the ends of the axes *a* and *b* are located by dropping perpendiculars from corresponding points above, and the length of the vertical axis 1·316 is laid off above and below *O* by means of the scale of decimal parts, at points marked *1* and – *1* in the figure. The lines of the linear projection needed for the two sets of axes are as follows: For the brachydome *o*, 011, the lines *xz* and *x′z′*, through *b* parallel to the *a* axis: For the macrodome *d*, 102

1038



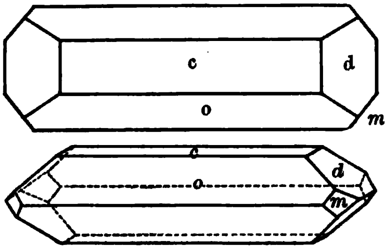
(2*a* : ∞ *b* : *c*), the lines *xy* and *x′y′*, through 2*a* parallel to the *b* axis: The prism *m* (110) is parallel to the vertical axis, hence in order that such a plane shall satisfy the conditions of the linear projection and pass through *unity on the vertical axis*, it must be considered as shifted (without change of direction) until it passes through the center: Its linear projection therefore is represented by the lines *yz* and *y′z′*, parallel to the directions 1*a* to 1*b* on the two sets of axes. Since a linear projection is made on the plane of the *a* and *b* axes, the intersection of any face with the base (001) has the same direction as the line representing its linear projection. It is well to note that the intersections *x*, *y* and *z* and *x′*, *y′* and *z′* are in vertical alignment with one another.

Concerning the drawing of figure 1038, it is a simple matter to proportion the general outline of the barite crystal in orthographic projection. The direction of the edge between *d*, 102, and *o*, 011, is determined by finding the point *x*, where the lines of the linear projection of *d* and *o* intersect, and drawing the edge parallel to the direction from *x* to the center *c*. The intersection of the prism *m*, 110, with *d* and *o* is a straight line, parallel to the direction 1*a* to 1*b* or *y* to *z*. To construct the clinographic figure, at some convenient point beneath the axes the horizontal middle edges of the crystal may be drawn parallel to the *a* and *b* axes, their lengths and intersections being determined by carrying down perpendiculars from the orthographic projection above. The intersection between *d*, 02, and *o*, 011, is determined by finding the point x' of the linear projection and drawing he edge parallel to the direction from x' to 1 (*unity*) on the vertical axis, while the corresponding direction below is parallel to the direction x' to -1. The size of the prism *m*, 10, and its intersections with *d* and *o* may all be determined by carrying down perpendiculars from the orthographic projection above, but it is well to control the directions by means of the linear projection: The edges between *m*, 110, and *d*, 102; and *m*, 110, and o, 011, are parallel respectively to the directions y' to *1* and z' to *1*. Having completed a figure, a copy free from construction lines may be had by placing the drawing over a clean sheet of paper and puncturing the intersections of all edges with a needle-point: An accurate tracing may then be made on the lower paper.

Should it happen that the linear projection made on the plane of the *a* and *b* axes gives intersections far removed from the center of the figure, a linear projection may be made on the clinographic axes either on the plane of the *a* and *c* or *b* and *c* axes, supposing that the faces pass, respectively, through *unity* on the *b* or the *a* axes.

Importance of an Orthographic in connection with a Clinographic Projection. — Many students, on commencing the study of crystallography, fail to derive the benefit they should from the figures given in text-books. Generally clinographic projections are given almost exclusively, with perhaps occasional basal or orthographic projections, and beginners find it hard to reconcile many of the figures with the appearance of the models and crystals which they are intended to represent. For example, given only the clinographic projection of barite, figure 1037, it takes considerable training and knowledge of the projection employed to gain from the figure a correct idea of the proportions of the crystal which it actually represents. This may be shown by comparing figures 1037 and 1039, which represent the same crystal, drawn one with the *a*, the other with the *b* axis to the front. It is seen from figure 1039 that the crystal is far longer in the direction of the *a* axis than one would imagine from inspection of only the clinographic projection of figure 1037. The front or *a* axis is much foreshortened in clinographic projection, consequently by the use of only this one kind of projection there is a two-fold tendency to err; on the one hand, in drawing, one is inclined to represent those edges running parallel to the *a* axis by lines which are considerably too long, while, on the other hand, in studying figures there is a tendency to regard them as representing crystals which are too much compressed in the direction of the *a* axis. By using orthographic in connection with clinographic projections these tendencies are overcome. Having in mind the proportions of a certain crystal, or having at hand a model, it is easy to construct an orthographic projection in which the *a* and *b* axes are represented with their true proportions; then the construction of a clinographic projection of correct proportions follows as a comparatively simple matter. Without an orthographic projection it would have been a difficult task to have constructed the clinographic projection of figure 1039 wth the proportions of the intercepts upon the *a* and *b* axes the same as in figure 1037, while with the orthographic projection orientated as in figure 1039 it was an easy matter. A combination of the two projections is preferable in many cases and from the two figures a proper conception of the development of the crystal may be had.

1039



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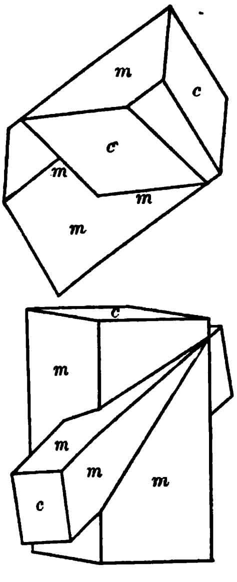
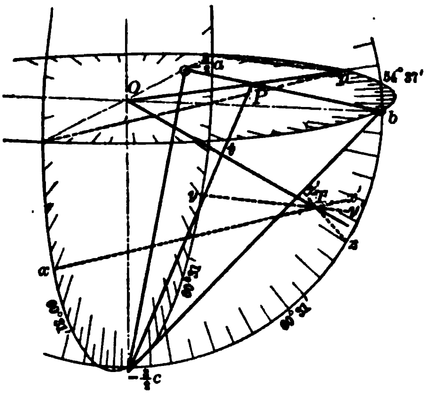


Drawing of Twin Crystals. — The axial protractor furnishes a convenient means for plotting the axes of twin crystals. The actual operation will differ with different problems but the general methods are the same. The two examples given will illustrate these methods.

(1). *To plot the axes for the staurolite twin shown in Fig. 1040.* In this case the twinning plane is parallel to the crystal face $\bar{2}3\bar{2}$ which has the axial intercepts of $-3/2a$, b, $-3/2c$. For staurolite, $a : b : c = 0{\cdot}473 : 1 : 0{\cdot}683$, while the ϕ and ρ angles of the twinning plane are, $\phi = 010 \wedge \bar{2}30 = 54° 37'$ and $\rho = 00\bar{1} \wedge \bar{2}3\bar{2} = 60° 31'$. To insure accuracy in plotting, the full lengths of the axes of the protractor have been regarded as unity. The first step is to locate on the clinographic projection the position of the twinning plane, $\bar{2}3\bar{2}$. This is shown in Fig. 1041 as the triangle from $-3/2a$ to b to $-3/2c$. The next step is to find the position of the twinning axis which will be normal to this plane. The coordinates of this twinning axis are given by the ϕ and ρ angles quoted above. The point p which is 54° 37′ back from the pole to 010 or b marks the place where the normal to the prism face $\bar{2}30$ would emerge from the sphere. The normal to $\bar{2}3\bar{2}$, which is the twinning axis will emerge on the meridian that runs through the point p and at such a distance below it that it will make the angle 60° 31′ with the negative end of the c axis. Chords are drawn to p from the points where the a and b axes meet the equator of the sphere and then chords parallel to these are drawn from the points x, y and z which are in each case 60° 31′ from the point where the negative end of the c axis cuts the spherical surface. The common meeting point of these chords T marks the place where the twinning axis pierces the spherical surface. The next step is to determine the point t at which the twinning axis cuts the twinning plane. The line OPp is by construction at right angles to the line connecting $-3/2a$ and $1b$. Therefore a vertical plane which is normal to the twinning plane would intersect that plane in the line connecting $-3/2c$ and P. The twinning axis OT would lie in this plane also. Consequently the point t, where OT and $-3/2c$–P intersect would lie both on the twinning axis and in the twinning plane. In order to make the method of construction clearer Fig. 1042 is given. Here the twinning axis is repeated from Fig. 1041. The twin position of the crystal is to be found by revolving it from its normal position through an arc of 180°, using the twinning axis as the axis of revolution. This will turn the twinning plane about upon the point t as a pivot and so transpose the points $-3/2a$, b and $-3/2c$ to points equidistant from it in an opposite position. By drawing lines through t and laying off equal distances beyond that point the new points $-3/2A$, B and $-3/2C$ will be obtained. These points lie upon the three axes in their twin position and so determine their directions.

1041



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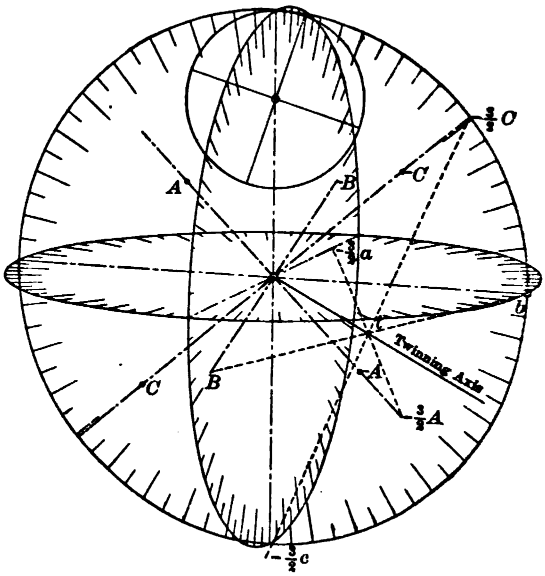
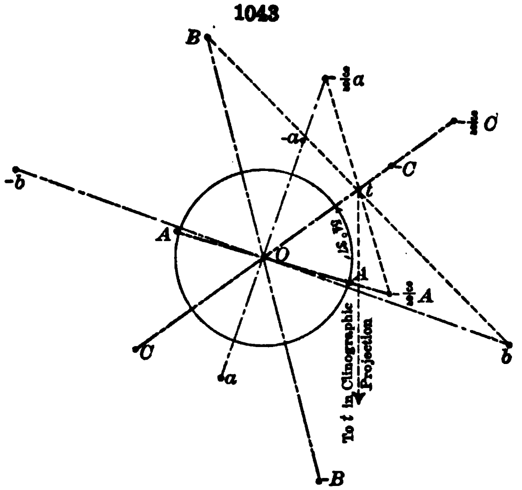


The plotting of the twin axes in the top view follows similar methods. In order to make the construction learer a separate figure, Fig. 1043, is given. The line O–t is laid off at an angle of 54° 37′ to the b axis. Upon this line the point t is found by projection upward from the clinographic view below. This point t then becomes the point around which the axes are revolved 180° to their twin positions. The figure shows clearly the methods of construction and the directions of the axes for the twin.

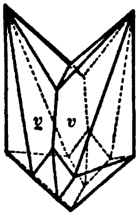
Upon the twin axes found in this way the portion of the crystal in twin position is drawn in exactly the same manner as if it was in the normal position.

(2). *To plot the axes for the calcite twin shown in Fig. 1044.* In this case it was desired to represent a scalenohedron twinned upon the rhombohedron f $(02\bar{2}1)$ and so drawn that the twinning plane should be vertical and have the position of b (010) of an orthorhombic crystal. The angle from c (001) to f $(02\bar{2}1)$ equals 63° 7′. In order to make the face f vertical, the vertical axis must be inclined at an angle of 26° 53′, or the angle between the c axes of the two individuals composing the twin would be double this or 53° 46′. These relations are shown in Fig 1045. As indicated in Fig. 1046 the position of these axes, c and C in the figure, are easily obtained at inclinations of 26° 53′ by use of the graduation of the vertical ellipse that passes through B and $-B$. The points X, X' and Y, Y' indicate the intersections with this same eclipse of the two planes containing the a_1, a_2 and a_3 axes in their respective inclined positions, the angles $-BX$, BX', and BY and $-BY'$ being in each case equal to 26° 53′. In order to have the twinning plane occupy a position parallel to the 010 plane of an orthorhombic crystal it is necessary to revolve the axes so that one of the a hexagonal axes shall coincide with the position of the a axis of the orthorhombic system, as $-a_3$, a_3 in Fig. 1046. The two other hexagonal axes corresponding to the axis c must therefore lie in a plane which includes $-a_3$, a_3 and the points X and X' and have such positions that they will make angles of 60° with $-a_3$, a_3. The construction necessary

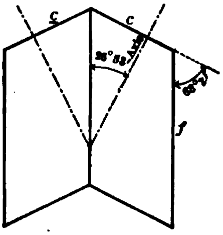
1043



1044



1045



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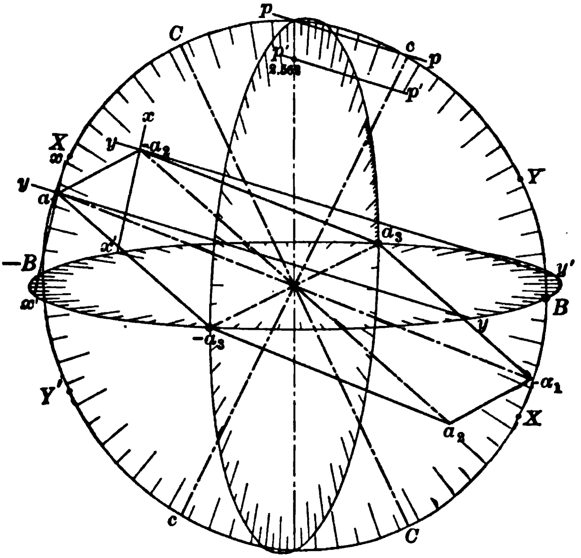

to determine the ends of these axes is as follows: Draw the two chords lettered x–x' through points that are 60° from $-a_3$ and a_3 and parallel to the direction of a chord that would pass through $-B$ and X. In a similar way draw the two chords y–y' through the second pair of points that are 60° from $-a_3$ and a_3, parallel to the direction of a chord that would pass through the points B and X.. The intersections of these two sets of chords determine the points a_1 and $-a_2$ which are the ends of these respective axes. The hexagon shown in the figure connects the ends of the a_1, a_2 and a_3 axes that lie in a plane perpendicular to the axis c. The set of axes that belong to the axis C are to be found in a similar way. The length of the vertical axis is to be obtained by multiplying that of calcite, c = 0·854, by three and laying off on the vertical line the length obtained or 2·562. This is transferred to the twin axis c by drawing the line p'–p' parallel to the line p–p. The desired figure of the calcite twin is to be drawn upon these two sets of inclined axes.

DRAWING CRYSTALS BY USE OF THE STEREOGRAPHIC AND GNOMONIC PROJECTIONS

The following explanation of the methods of drawing crystals from the projections of their forms has been taken with only minor modifications from Penfield's description.*

1. USE OF THE STEREOGRAPHIC PROJECTION

In explaining the method, a general example has been chosen; the construction of a drawing of a crystal of axinite, of the triclinic system. Figure 1047A represents a stereographic projection of the ordinary forms of axinite, *m* (110), *a* (100), *M* ($1\bar{1}0$), *p* (111), *r* ($1\bar{1}1$) and *s* (201). As shown by the figure, the *first meridian*, locating the position of 010, has been chosen at 20° from the horizontal direction *SS'*.

Figure 1047B is a *plan*, or an orthographic projection of an axinite crystal, as it appears when looked at in the direction of the vertical axis. It may be derived from the stereographic projection in a simple manner, as follows: — The direction of the parallel edges made by the intersections of the faces in the zone *m*, *s*, *r*, *m'*, A, is parallel to a tangent at either *m* or *m'*, and this direction may be had most easily by laying a straight edge from *m* to *m'* and, by means of a 90° triangle, transposing the direction to B, as shown by the construction.

The construction of C, which may be called a *parallel-perspective* view, may next be explained: It is not a clinographic projection like the usual crystal drawings from axes, but an orthographic projection, made on a plane intersecting the sphere, represented by the stereographic projection, A, along the great circle *SES'*; the distance *EC* being 10°. The plane on which a drawing is to be made may, of course, have any desired inclination or position, but by making the distance *CE* equal 10° and taking the first meridian at 20° from *S*, almost the same effects of plan and parallel perspective are produced as in the conventional method of drawing from axes, where the eye is raised 9° 28' and the crystal turned 18° 26'.

The easiest way to explain the construction of C from A is to imagine the sphere, represented by the stereographic projection, as revolved 80° about an axis joining *S* and *S'*, or until the great circle *SES'* becomes horizontal. After such a revolution, the stereographic projection shown in A would appear as in D, and the parallel-perspective drawing, E, could then be derived from D in exactly the same manner as B was derived from A. This is, for example, because the great circle through *m*, *s* and *r*, D, intersects the graduated circle at *x*, where the pole of a vertical plane in the same zone would fall, provided one were present; hence the intersection of such a surface with the horizontal plane, and, consequently, the direction of the edges of the zone, would be parallel to a tangent at *x*: In other words, E is a *plan* of a crystal in the position represented by the stereographic projection, D. Although not a difficult matter to transpose the poles of a stereographic projection so as to derive D from A, it takes both time and skill to do the work with accuracy, and it is not at all necessary to go through the operation. To find the direction of the edges of any zone in C, for example *m s r*, note first in A the point *x*, where the great circles *m s r* and *SES'* cross. During the supposed revolution of 80° about the axis *SS'*, the pole *x* follows the arc of a small circle and falls finally at *x'* (the same position as *x* of D) and a line at right angles to a diameter through *x'*, as shown by the construction, is the desired direction for C. Similarly for the zones *pr*, *MrM'* and *MspM'*, their intersections with *SES'* at *w*, *y* and *z* are transposed by the revolution of 80° to *w'*, *y'* and *z'*. The transposition of the poles *w*, *x*, *y* and *z*, A, to *w'*, *x'*, *y'* and *z'* may easily be accomplished in the following ways: — (1) By means of the Penfield transparent, small-circle protractor (Fig. 68, p. 39) the distances of w, x, y and z from either S or S' may be determined and the corresponding number of degrees counted off on the graduated circle. (2)

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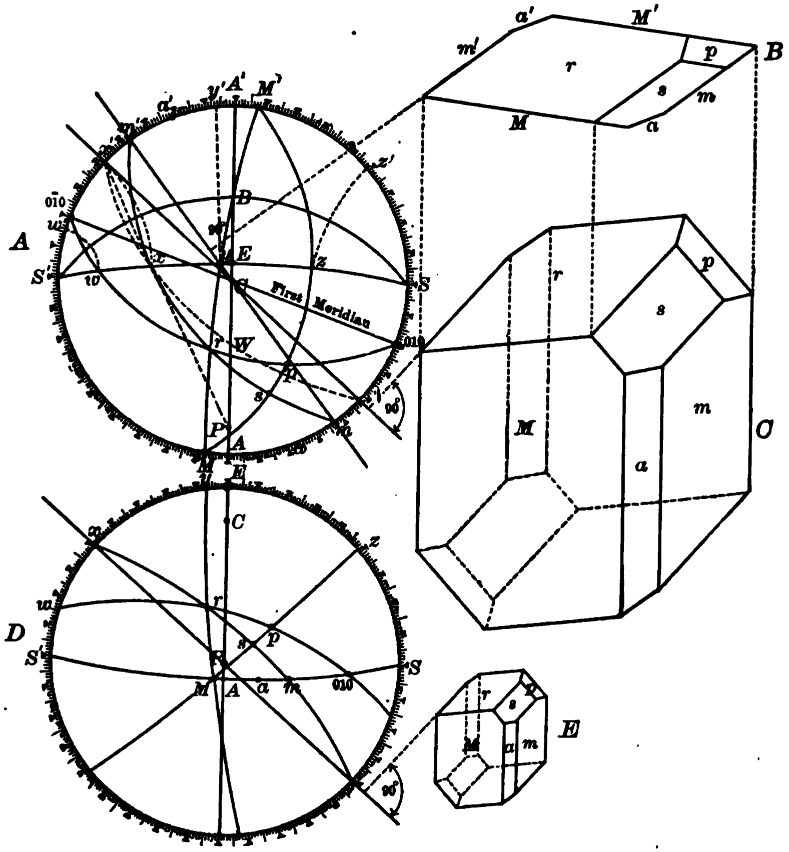
* Am. J. Sc., **21**, 206, 1906.

1047

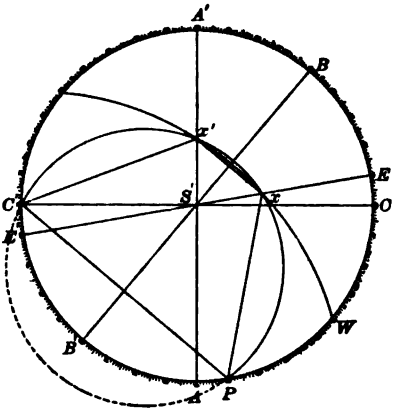


Development of a plan and parallel-perspective figure of axinite, triclinic system from a stereographic projection (after Penfield)

Find first the pole P of the great circle SES', where P is 90° from E or 80° from C, and is located by means of a stereographic scale or protractor (Fig. 62, p. 35): A straight line drawn through P and x will so intersect the graduated circle at x', that $S'x$ and $S'x'$ are equal in degrees. The reason for this is not easily comprehended from A, but if it is imagined that the projection is revolved 90° about an axis AA', so as to bring S' at the center, the important poles and great circles to be considered will appear as in figure 1048, where P and C' are the poles, respectively, of the great circles $ES'E'$ and $AS'A'$, and x is 41¼° from S' as in figure 1047A. It is evident from the symmetry of figure 1048 that a plane surface touching at C', P and x will so intersect the great circle $AS'A'$ that the distances $S'x$ and $S'x'$ are equal. Now a plane passing through C', P, x and x', if extended, would intersect the sphere as a small circle, shown in the figure, but since this circle passes through C', which in figure 1047A is the pole of the stereographic projection (antipodal to C), it will be projected in figure A as a straight line, drawn through P and x, since the intersections upon the plane of projection of all planes that pass through the point of vision of the projection will appear as straight lines. (3) In figure 1048 B is located midway between E

and *A'*, *BS'B'* is a great circle, and *W*, 40° from *C*, is its pole: It is now evident from the symmetry of the figure that a great circle through *W* and *x* so intersects the great circle *AS'A'*, that the distances *S'x* and *S'x'* are equal. Transferring the foregoing relations to figure 1047A, *W*, 40° from *C*, is the pole of the great circle *SBS'*, and a great circle drawn through *W* and *x* falls at *x'*. However, it is not necessary to draw the great circle through *W* and *x* to locate the point *x'* on the graduated circle: By centering the Penfield transparent great circle protractor, (Fig. 67, p. 39) at *C*, and turning it so that *W* and *x* fall on the same great circle, the point *x* may be transposed to *x'*, and other points, *w'*, *y'* and *z'*, would be found in like manner.

1048



The three foregoing methods of transposing *x* to *x'*, *z* to *z'*, etc., are about equally simple, and it may be pointed out that, supplied with transparent stereographic protractors, and having the poles of a crystal plotted in stereographic projection, it is only necessary to draw the great circle *SES'* and to locate one point, either *W* or *P*, in order to find the directions needed for a parallel-perspective drawing, corresponding to figure 1047C. Thus, with only a great circle protractor, the great circle through the poles of any zone may be traced, and its intersection with *SES'* noted and spaced off with dividers from either *S* or *S'*; then the great circle through the intersection just found and *W* is determined, and where it falls on the divided circle noted, when the desired direction may be had by means of a straight edge and 90° triangle, as already explained.

2. Drawing of Twin Crystals by Use of the Stereographic Projection

In the great majority of cases the drawing of twin crystals can be most advantageously accomplished by the use of a stereographic projection of their forms. It is only necessary first to prepare a projection showing the poles of the faces in the normal and twin positions and then follow the methods outlined above. The preparation of the desired projection may, however, need some explanation. An illustrative example is given below taken from an article by Ford and Tillotson on some Bavenno twins of orthoclase.*

According to the Baveno law of twinning the *n* (021) face becomes the twinning plane and as the angle $c \wedge n = 44° 56\ 1/2'$ the angle between *c* and *c'* (twin position) becomes 89° 53'. For the purposes of drawing it is quite accurate enough to assume that this angle is exactly 90° and that accordingly the *c* face of the twin will occupy a position parallel to that of the *b* face of the normal individual.

Fig. 1049 shows the forms observed of the crystals both in normal and in twin positions, the faces in twin position being indicated by open circles and a prime mark (') after their respective letters, while the zones in twin position are drawn in dashed lines. Starting out with the forms in normal position, the first face to transpose is the base *c*. This form, from the law of the twinning, will be transposed to *c'* where it occupies the same position as *b* of the normal individual, and it necessarily follows that *b* itself in being transposed will come to *b'* at the point where the normal *c* is located.

In turning therefore the crystal to the left from normal to twin position, the fades *c* and *b* travel along the great circle I through an arc of 90° until they reach their respective twin positions. We have, in other words, revolved the crystal 90° to the left about an axis which is parallel to the faces of the zone I. The pole of this axis is located on the stereographic projection at 90° from the great circle I and falls on the straight line II, another great circle which intersects zone I at right angles. This pole *P* is readily located by the stereographic protractor on the great circle II at 90° from *c*. The problem then is to revolve the poles of the faces from their normal positions about the point *P* to the left and through an arc of 90° in each case.

During the revolution the poles of the *n* faces remain on the great circle I and as the angle $n \wedge n = 90°$, the location of their poles when in twin position is identical with that of the normal position and *n'* falls on top of *n*. We can now transpose the great circle II from its normal to its twin position, since *P* remains stationary during the revolution and we have determined the twin position of *c*. The dashed arc II' gives the twin position of the great circle II. The twin position of *y* must lie on arc II' and can be readily located at *y'*, the intersection of arc II' with a small circle about *P* having the radius $P \wedge y$. It is now possible to construct the arc of the zone III in its transposed position III', for we have two of the points, *y'* and *n'* of the latter, already located. By the aid of the Penfield transparent great circle protractor the position of the arc of the great circle on which these two points lie can be determined. On this arc, III', *o'* and *m'* must also lie. Their positions are most easily determined by drawing arcs of small circles about *b'* with the required radii, $b \wedge o = 63° 8'$, $b \wedge m = 59° 22\ 1/2'$ and the points at which they intersect arc III' locate the position of the poles *o'* and *m'*. At the same time the corresponding points on IV' may be located, it being noted that IV' and III are the same arc. But one other form remains to be transposed, the prism *z*. We have already *b'* and *m'* located and it is a simple matter with the aid of the great circle protractor to determine the position of the great circle upon which they lie. Then a small circle about *b'* with the proper radius, $b \wedge z = 29° 24'$, determines at once by its intersections with this arc the position of the poles of the *z* faces.

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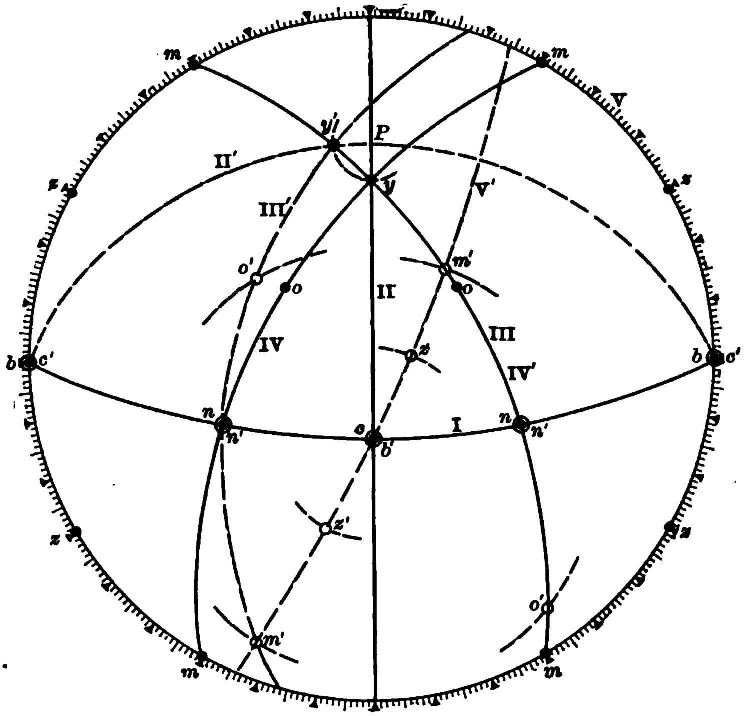
* Am. J. Sc., **26**, 149, 1908.

1049

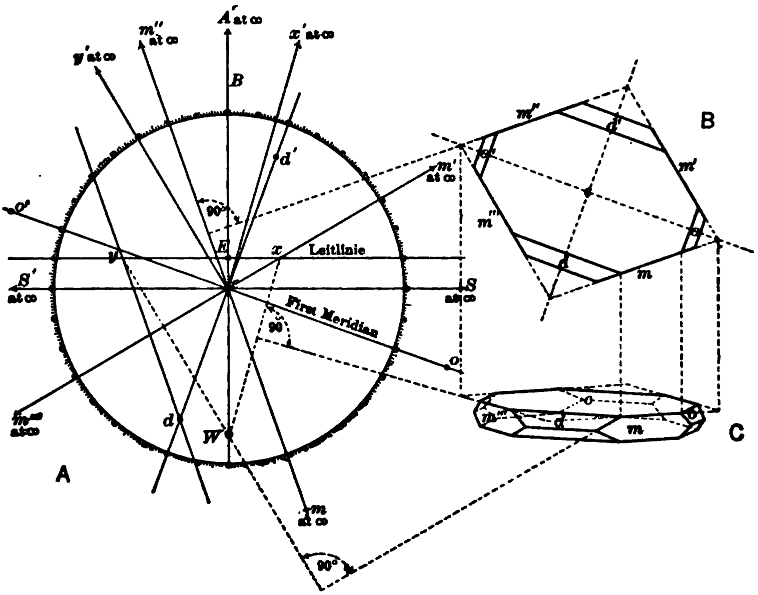


It may be pointed out that if it should be desired to make use of the methods of the gnonomic projection for the drawing of the figures as described below, the stereographic projection of the forms may be readily transformed into a gnomonic projection by doubling the angular distance from the center of the projection to each pole by the use of the stereographic protractor, Fig. 62, p. 35.

3. Use of the Gnomonic Projection

As an illustration, the method of drawing a simple combination of barite has been chosen. The forms shown in figure 1050 are *c* (001), *m* (110), *o* (011) and *d* (102). The location of the poles in the gnomonic projection is shown in A, where, as in figure 1047A, the *first* *meridian* is taken at 20° from the horizontal direction SS'. The poles of the prism m and the locations of S and S' (compare figure 1047A) fall in the gnomonic projection at infinity. In any plan, such as figure 1050B, the direction of an edge made by the meeting of two faces is at right angles to a line joining the poles of the faces, shown in figures A and B by the direction at 90° to the line joining m'' and c.

1050



The parallel-perspective view, 1050C, is an orthographic projection (compare figures 1047A and C) drawn on a plane passing through S and S', and intersecting the sphere on which the gnomonic projection is based as a great circle passing through E, figure 1050A, and drawn parallel to SS', the distance cE being 10°: This great circle is called by Goldschmidt the *Leitlinie*. To find such intersections as between m''' and c, and m and d, figure C, note, as in figure 1047A, where the great circles through the poles of the faces intersect the *Leitlinie;* thus, the one through m''' and c at x, and that through m and d (through d parallel to $m\,m''$, since m and m'' are at infinity) at y. Next imagine the points x and y transposed as in figure 1047A to x' and y', which latter points, however, are located at infinity: This transposition is done by locating first the so-called *Winkelpunkt*, W, of Goldschmidt, 40° from c in figure 1050A, and as in figure 1047A, 90° from a point B, which is an equal number of degrees from E and A' (compare figure 1048). Of the three methods given above for transposing x and y to x' and y', the third may be easily applied in the gnomonic projection. Great circles, or straight lines, through W and x and W and y, figure 1050A, if continued to infinity, would determine x' and y', which is accomplished by drawing lines parallel to Wx and Wy through the center. It is not necessary, however, to draw the lines Wx and Wy, nor the parallel lines through the center; all that is needed to find the directions of the edges $m''' \wedge c$ and $m \wedge d$ is to lay a straight edge from W to x, respectively W to y, and with a 90° triangle transpose the directions to C, as indicated in the drawings. The principles are exactly the same as worked out for the interrelations of figures 1047A and C. As in the case of the stereographic projection, it is evident that, given the poles of a crystal plotted in the gnomonic projection, it would be necessary to draw only one line, the *Leitlinie*, and to locate one point, the *Winkelpunkt*, W, in order to find all possible directions for a plan and parallel-perspective views, corresponding to figures 1050B and C.

APPENDIX B

TABLES USEFUL IN THE DETERMINATION OF MINERALS

This Appendix contains a series of tables, more or less complete, of minerals arranged according to chemical composition or to certain prominent crystallographic or physical characters. These, it is believed, will be of service not only to the student, but also to the skilled mineralogist.

The type used in the printing of the mineral names indicates their relative importance. Table I is a complete list of the species named in this book arranged first according to the prominent basic elements which they contain and secondly according to their acid radicals. Table II is of Minerals arranged according to their System of Crystallization. The other tables make no claim to completeness, being limited often to common and important species.

For an exhaustive system of Determinative Tables based particularly upon blowpipe and chemical characters, the student is referred to the work of Professors Brush and Penfield, mentioned on p. 330.

TABLE I. MINERALS ARRANGED ACCORDING TO CHEMICAL COMPOSITION

The following lists include all definitely described mineral species arranged first according to their important basic elements and secondly according to their acid radicals. If a given mineral contains two or more prominent bases its name is repeated in all the appropriate sections.

ALUMINIUM

Note: — Aluminium is of such common occurrence among the silicate minerals that it is impracticable to list all of these minerals that contain it. Therefore only those silicates which are essentially aluminium minerals are included in the following list.

Chloralluminite, $AlCl_3.6H_2O$.
CRYOLITE, Na_3AlF_6.
Koenenite, Al,Mg, oxychloride.
Fluellite, $AlF_3.H_2O$.
Prosopite, $CaF_2.2Al(F,OH)_3$.
Pachnolite, Thomsenolite, $NaF.CaF_2.AlF_3.H_2O$.
Gearksutite, $CaF_2.Al(F,OH)_3.H_2O$.
Ralstonite, $(Na_2,Mg)F_2.3Al(F,OH)_3.2H_2O$.
Creedite, $2CaF_2.2Al(F,OH)_3.CaSO_4.2H_2O$.
Corundum, Al_2O_3.
Spinel, $MgO.Al_2O_3$.
Hercynite, $FeO.Al_2O_3$.
Gahnite, $ZnO.Al_2O_3$.
Chrysoberyl, $BeO.Al_2O_3$.
Uhligite, $Ca(Ti,Zr)O_5.Al\ (Ti,Al)O_5$.
DIASPORE, $Al_2O_3.H_2O$.
Bauxite, $Al_2O_3.2H_2O$.
GIBBSITE, $Al_2O_3.3H_2O$.
Hydrotalcite, $Al(OH)_3.3Mg(OH)_2.3H_2O$.
Shanyavskite, $Al_2O_3.4H_2O$.
Dundasite, $Pb(AlO)_2(CO_3)_2$.
Dawsonite, $Na_3Al(CO_3)_3.2Al(OH)_3$.
Zunyite, $(Al(OH,F,Cl)_2)_6Al_2Si_3O_{12}$.
Topaz, $[Al(F,OH)]_2SiO_4$.
ANDALUSITE, Al_2SiO_5.
SILLIMANITE, Al_2SiO_5.
Cyanite, Al_2SiO_5.
Dumortierite, $8Al_2O_3.B_2O_3.6SiO_2.H_2O$.
Staurolite, $(AlO)_4(AlOH)Fe(SiO_4)_2$.
Kaolinite, $H_4Al_2Si_2O_9$.
Faratsihite, $(Al,Fe)_2O_3.2SiO_2.2H_2O$.
Halloysite, $H_4Al_2Si_2O_9.H_2O$.
Newtonite, $H_8Al_2Si_2O_{11}.H_2O$.
Cimolite, $2Al_2O_3.9SiO_2.6H_2O$.
Montmorillonite, $H_2Al_2Si_4O_{12}.nH_2O$.

PYROPHYLLITE, $H_2Al_2(SiO_3)_4$.
Allophane, $Al_2SiO_5.5H_2O$.
Melite, $2(Al,Fe)_2O_3.SiO_2.8H_2O$.
Collyrite, $2Al_2O_3.SiO_2.9H_2O$.
Schrötterite, $8Al_2O_3.3SiO_2.30H_2O$.
Hamlinite, Al,Sr, phosphate
Plumbogummite, Pb,Al, phosphate.
Florencite, Al,Ce, phosphate.
Georceixite, $BaO.2Al_2O_3.P_2O_5.5H_2O$.
Crandallite, $2CaO.4Al_2O_3.2P_2O_5.10H_2O$.
Harttite, $(Sr,Ca)O.2Al_2O_3.P_2O_5.SO_3.5H_2O$.
Durangite, $Na(AlF)AsO_4$.
Amblygonite, $Li(AlF)PO_4$
Fremontite, $(Na,Li)Al(OH,F)PO_4$.
Lazulite, $2AlPO_4.(Fe,Mg)(OH)_2$.
Tavistockite, $Ca_3P_2O_8.2Al(OH)_3$.
Cirrolite, $Ca_3Al(PO_4)_3.Al(OH)_3$.
Synadelphite, $2(Al,Mn)AsO_4.5Mn(OH)_2$.
Hematolite, $(Al,Mn)AsO_4.4Mn(OH)_2$.
Barrandite, $(Al,Fe)PO_4.2H_2O$.
Variscite, $AlPO_4.2H_2O$.
Lucinite, $AlPO_4.2H_2O$.
Callainite, $AlPO_4.2\frac{1}{2}H_2O$.
Zepharovichite, $AlPO_4.3H_2O$.
Palmerite, $HK_2Al_2(PO_4)_3.7H_2O$.
Rosiérésite, Hydrous, Al,Pb,Cu, phosphate.
WAVELLITE, $4AlPO_4.2Al(OH)_3.9H_2O$.
Fischerite, $AlPO_4.Al(OH)_3.2\frac{1}{2}H_2O$.
Peganite, $AlPO_4.Al(OH)_3.1\frac{1}{2}H_2O$.
TURQUOIS, $CuO.3Al_2O_3.2P_2O_5.9H_2O$.
Wardite, $2Al_2O_3.P_2O_5.4H_2O$.
Sphærite, $4AlPO_4.6Al(OH)_3$.
Liskeardite, $(Al,Fe)AsO_4.2(Al,Fe)(OH)_3.5H_2O$.
Evansite, $2AlPO_4.4Al(OH)_3.12H_2O$.
Cœruleolactite, $3Al_2O_3.2P_2O_5.10H_2O$.
Angelite, $2Al_2O_3.P_2O_5.3H_2O$.
Berlinite, Trolleite, Attacolite | Hydrous
Minasite, Vashegyite | Alphosphates
Soumansite, Hydrous, Al, Na, fluo-phosphate.
Childrenite, $2AlPO_4.2Fe(OH)_3.2H_2O$.
Eosphorite, $2AlPO_4.2(Mn,Fe)(OH)_3.2H_2O$.
Egueiite, Hydrous, Fe,Al,Ca, phosphate.
Liroconite, $Cu_6Al(AsO_4)_5.3CuAl(OH)_5.20H_2O$.
Henwoodite, Al,Cu, hydrous phosphate.
Ceruleite, $CuO.2Al_2O_3.As_2O_5.8H_2O$.
Kehoite, Hydrous, Al,Zn, phosphate.
Goyazite, $Ca_3Al_{10}P_2O_{23}.9H_2O$.
Roschérite, $(Mn,Fe,Ca)_2Al(OH)(PO_4)_2.2H_2O$.
Svanbergite, Hydrous Al, Ca, phosphate and sulphate.
Teremejevite, $AlBO_3$.
Rhodizite, Al,K, borate.
Millosevichite, $(Fe,Al)_2(SO_4)_3$.
Spangolite, $Cu_6AlClSO_{10}.9H_2O$.
Alumian, $Al_2O_3.2SO_3$.
Kalinite, $KAl(SO_4)_2.12H_2O$.
Tschermigite, $(NH_4)Al(SO_4)_2.12H_2O$.
Mendozite, $NaAl(SO_4)_2.12H_2O$.
Pickeringite, $MgSO_4.Al_2(SO_4)_3.22H_2O$.
Halotrichite, $FeSO_4.Al_2(SO_4)_3.24H_2O$.
Apjohnite, $MnSO_4.Al_2(SO_4)_3.24H_2O$.
Dietrichite, $(Zn,Fe,Mn)SO_4.Al_2(SO_4)H_3.22_2O$.
Alunogen, $Al_2(SO_4)_3.18H_2O$.
Cyanotrichite, $4CuO.Al_2O_3.SO_3.8H_2O$.
Knoxvillite, Hydrous, Fe,Al,Cr, sulphate.
Cyprusite, $7Fe_2O_3.Al_2O_3.10SO_3.14H_2O$.
Aluminite, $Al_2O_3.SO_3.9H_2O$.
Paraluminite, $2Al_2O_3.SO_3.10H_2O$.
Felsöbanyite, $2Al_2O_3.SO_3.10H_2O$.
Voltaite, $3(K_2,Fe)O.2(Al,Fe)_2O_3.6SO_3.9H_2O$.
ALUNITE, $K_2Al_6(OH)_{12}.(SO_4)_4$.
Löwigite, $K_2O.3Al_2O_3.4SO_3.9H_2O$.
Almeriite, $Na_2SO_4.Al_2(SO_4)_3.5Al(OH)_3.H_2O$.
Ettringite, $6CaO.Al_2O_3.3SO_3.33H_2O$.
Zincaluminite, $2ZnSO_4.4Zn(OH)_2.6Al(OH)_3.5H_2O$.
Mellite, $Al_2C_{12}O_{12}.18H_2O$.

ANTIMONY

NOTE: — The antimonates are not included in this list.

Allemontite, $SbAs_3$.
NATIVE ANTIMONY, Sb.
Stibnite, Sb_2S_3.
Kermesite, Sb_2S_2O.
Senarmontite, Valentinite, Sb_2O_3.
Cervantite, $Sb_2O_3.Sb_2O_5$.
Stibiconite, $H_2Sb_2O_5$.
Stibiotantalite, $(SbO)_2(Ta,Nb)_2O_6$.

ARSENIC

NOTE: — The arsenates are not included in this list.

NATIVE ARSENIC, As.
Allemontite, $SbAs_3$.
REALGAR, AsS.
ORPIMENT, As_2S_3.
Arsenopyrite, FeAsS.
Arsenolite, Claudetite, As_2O_3.

BARIUM

Witherite, $BaCO_3$.
Bromlite, $(Ba,Ca)CO_3$.
Barytocalcite, $BaCO_3.CaCO_3$.
Hyalophane, $(K_2,Ba)Al_2(SiO_3)_4$.
Celsian, $BaAl_2Si_2O_8$.
Cappelenite, Y,Ba, boro-silicate.
Hyalotekite, $(Pb,Ba,Ca)B_2(SiO_3)_{12}$.
Barylite, $Ba_4Al_4Si_7O_{24}$.
Taramellite, $Ba_4Fe'' Fe_4''' Si_{10}O_{31}$.
Brewsterite, $H_4(Sr,Ba,Ca)Al_2(SiO_3)_6.3H_2O$.
Wellsite, $(Ba,Ca,K_2)Al_2Si_3O_{10}.3H_2O$.
Harmotone, $(K_2,Ba)Al_2Si_5O_{14}.5H_2O$.
Edingtonite, $BaAl_2Si_3O_{10}.3H_2O$.
Benitoite, $BaTiSi_3O_9$.
Leucosphenite, $Na_4Ba(TiO)_2(Si_2O_5)_5$.
Georceixite, $BaO.2Al_2O_3.P_2O_5.5H_2O$.
Ferrazite, $3(Ba,Pb)O.2P_2O_5.8H_2O$.
Volborthite, Cu,Ba,Ca, vanadate.
Uranocircite, $Ba(UO_2)_2P_2O_8.8H_2O$.
Nitrobarite, $Ba(NO_3)_2$.
Barite, $BaSO_4$.

BERYLLIUM

Chrysoberyl, $BeAl_2O_4$.
Eudidymite, Epididymite, $HNaBeSi_3O_8$.
Beryl, $Be_3Al_2(SiO_3)_6$.
$\left.\begin{array}{l}\text{Leucophanite}\\ \text{Meliphanite}\end{array}\right\}$ Be,Ca,Na, silicates.
Helvite, $(Be,Mn,Fe)_7Si_3O_{12}S$.
Danalite, $(Be,Fe,Zn,Mn)_7Si_3O_{12}S$.
Phenacite, Be_2SiO_4.
Trimerite, $(Mn,Ca)_2SiO_4.Be_2SiO_4$.
Euclase, $HBeAlSiO_5$.
Gadolinite, $Be_2FeY_2Si_2O_{10}$.
Bertrandite, $H_2Be_4Si_2O_9$.
Beryllonite, $NaBePO_4$.
Herderite, $Ca[Be(F,OH)]PO_4$.
Hambergite, $Be_2(OH)BO_3$.

BISMUTH

Native Bismuth, Bi.
Bismuthinite, Bi_2S_3.
Guanajuatite, Bi_2Se_3.
Tetradymite, $Bi_2(Te,S)_3$.
Grünlingite, Bi_4TeS_3.
Josēite, Wehrlite, bismuth tellurides.
Daubreete, Bi, oxychloride.
Bismite, Bi_2O_3.
Bismutospärite, $Bi_2(CO_3)_3.2Bi_2O_3$.
Bismutite, $Bi_2O_3.CO_2.H_2O$.
Eulytite, Agricolite, $Bi_4Si_3O_{12}$.
Pucherite, $BiVO_4$.
Atelestite, $H_2Bi_3AsO_8$.
Walpurgite, $Bi_{10}(UO_2)_3(OH)_{24}(AsO_4)_4$.
Rhagite, $2BiAsO_4.3Bi(OH)_3$.
Arseno-bismite, hydrous Bi arsenate.
Mixite, Hydrous Cu, Bi, arsenate.
Uranosphærite, $(BiO)_2U_2O_7.3H_2O$.
Montanite, $Bi_2O_3.TeO_3.2H_2O$.
Koechlinite, $Bi_2O_3.MoO_3$.

BORON

Note: — The borates are not included in this list.

Sassolite, $B(OH)_3$.
Cappelenite, Y,Ba, boro-silicate.
Hyalotekite, $(Pb,Ba,Ca)B_2(SiO_3)_{12}$.
Danburite, $CaB_2(SiO_4)_2$.
Datolite, $HCaBSiO_5$.
Homilite, $Ca_2FeB_2Si_2O_{10}$.
Axinite, Ca,Al, boro-silicate.
Tourmaline, complex boro-silicate.
Dumortierite, $8Al_2O_3.B_2O_3.6SiO_2.H_2O$.
Serendibite, $10(Ca,Mg)O.5Al_2O_3.B_2O_3.6SiO_2$.
Manandonite, $H_44Li_4Al_{14}B_4.Si_6O_{53}$.
Bakerite, Hydrous Ca, boro-silicate.
Searlesite, $NaB(SiO_3)_2.H_2O$.
Lüneburgite, $3MgO.B_2O_3.P_2O_5.8H_2O$.

CADMIUM

Greenockite, CdS.
Cadmiumoxide, CdO.
Otavite, Cd carbonate.

CÆSIUM

Pollucite, $2Cs_2O.2Al_2O_3.9SiO_2.H_2O$.
Rhodizite, Al,K,Cs, borate.

CALCIUM

Oldhamite, CaS.
Fluorite, CaF_2.
Hydrophilite, $CaCl_2$.
Yttrofluorite, $(Ca_3,Y_2)F_6$.
Nocerite, $2(Ca,Mg)F_2.(Ca,Mg)O$.
Tachhydrite, $CaCl_2.2MgCl_2.12H_2O$.
Prosopite, $CaF_2.2Al(F.OH)_3$.
Pachnolite, Thomsenolite, $NaF.CaF_2.AlF_3.H_2O$.
Gearksutite, $CaF_2.Al(F,OH)_3.H_2O$.
Creedite, $2CaF_2.2Al(F,OH)_3.CaSO_4.2H_2O$.
Yttrocerite, $(Y,Er,Ce)F_3.5CaF_2.H_2O$.
Uhligite, $Ca(Ti,Zr)O_5.Al(Ti,Al)O_5$.
Calcite, $CaCO_3$.
Dolomite, $CaCO_3.MgCO_3$.
Ankerite, $CaCO_3.(Mg,Fe,Mn)CO_3$.
Aragonite, $CaCO_3$.
Bromlite, $(Ba,Ca)CO_3$.
Barytocalcite, $BaCO_3.CaCO_3$.
Parisite, $[(Ce,La,Di)F]_2Ca(CO_3)_2$.
Pirssonite, $CaCO_3.Na_2CO_3.2H_2O$.
Gay-Lussite, $CaCO_3.Na_2CO_3.5H_2O$.
Gajite, basic, hydrous, Ca, Mg, carbonate.
Uranothallite, $2CaCO_3.U(CO_3)_2.10H_2O$.
Liebigite, Hydrous Ca,U, carbonate.
Voglite, Hydrous U,Ca,Cu, carbonate.
Milarite, $HKCa_2Al_2(Si_2O_5)_6$.
Rivaite, $(Ca,Na_2)Si_2O_5$.
$\left.\begin{array}{l}\textbf{Oligoclase}\\ \textbf{Andesine}\\ \textbf{Labradorite}\end{array}\right\}$ Mixtures of $NaAlSi_3O_8$ and $CaAl_2Si_2O_8$.
Anorthite, $CaAl_2Si_2O_8$.
Anemousite, $Na_2O.2CaO.3Al_2O_3.9SiO_2$.
Pyroxene, Ca,Mg, etc., silicate.
Wollastonite, $CaSiO_3$.
Pectolite, $HNaCa_2(SiO_3)_3$.
Schizolite, $HNa(Ca,Mn)_2(SiO_3)_3$.
Rosenbuschite, near pectolite with Zr.
Wöhlerite, Zr-silicate and niobate of Ca,Na.
Låvenite, Zr-silicate of Mn,Ca.
Babingtonite, $(Ca,Fe,Mn)SiO_3$ with $Fe_2(SiO_3)_3$.
Hiortdahlite, $(Na_2,Ca)(Si,Zr)O_3$.
Amphibole, Ca, Mg, etc., silicate.
Arfvedsonite, Na,Ca,Fe, silicate.
$\left.\begin{array}{l}\text{Leucophanite}\\ \text{Meliphanite}\end{array}\right\}$ Na,Be,Ca, fluo-silicate.
Custerite, $Ca_2(OH,F)SiO_3$.
Didymolite, $2CaO.3Al_2O_3.9SiO_2$.
Ganomalite, $Pb_4(PbOH)_2Ca_4(Si_2O_7)_3$.
Nasonite, $Pb_4(PbCl)_2Ca_4(Si_2O_7)_3$.
Margarosanite, $Pb(Ca,Mn)_2(SiO_3)_3$.
Hardystonite, $Ca_2ZnSi_2O_7$.
Rocblingite, $5(H_2CaSiO_4).2(CaPbSO_4)$.
Haüynite, $Na_2Ca(NaSO_4.Al)Al_2(SiO_4)_3$.
Grossularite, $Ca_3Al_2(SiO_4)_3$.
Andradite, $Ca_3Fe_2(SiO_4)_3$.

UVAROVITE, $Ca_3Cr_2(SiO_4)_3$.
Schorlomite, $Ca_3(Fe,Ti_2)[(Si,Ti)O_{43}]$.
Monticellite, $CaMgSiO_4$.
Glaucochroite, $CaMnSiO_4$.
Trimerite, $(Mn,Ca)_2SiO_4.Be_2SiO_4$.
SCAPOLITE GROUP, Mixtures of $Ca_4Al_6Si_6O_{25}$ and $Na_4Al_3Si_9O_{24}Cl$.
Sarcolite, $(Ca,Na_2)_3Al_2(SiO_4)_3$.
Melilite, $Na_2(Ca,Mg)_{11}(Al,Fe)_4(SiO_4)_9$.
Cebollite, $H_2Ca_4Al_2Si_3O_{16}$.
Gehlenite, $Ca_3Al_2Si_2O_{10}$.
Vesuvianite, $Ca_6[Al(OH,F)]Al_2(SiO_4)_5$.
DANBURITE, $CaB_2(SiO_4)_2$.
Guarinite, $2(K,Na)_2O.8CaO.5(Al,Fe,Ce)_2O_3.10SiO_2$.
Datolite, $HCaBSiO_5$.
Homilite, $Ca_2FeB_2Si_2O_{10}$.
ZOISITE, $Ca_2(AlOH)Al_2(SiO_4)_3$.
Epidote, $Ca_2[(Al,Fe)OH](Al,Fe)_2(SiO_4)_3$.
Piedmontite, $Ca_2(AlOH)(Al,Mn)_2(SiO_4)_3$.
Allanite, $(Ca,Fe)_2(AlOH)(Al,Ce,Fe)_2(SiO_4)_3$.
AXINITE, Ca,Al, boro-silicate.
PREHNITE, $H_2Ca_2Al_2(SiO_4)_3$.
Harstigite, Mn,Ca, silicate
Cuspidine, $Ca_2Si(O,F_2)_4$.
ILVAITE, $CaFe_2(FeOH)(SiO_4)_2$.
Clinohedrite, $H_2CaZnSiO_5$.
Stokesite, $H_4CaSnSi_3O_{11}$.
Lawsonite, Hibschite, $H_4CaAl_2Si_2O_{10}$.
Beckelite, $Ca_3(Ce,La,Di)_4Si_3O_{15}$.
Angaralite, $2(Ca,Mg)0.5(Al.Fe)_2O_3.6SiO_2$.
Serendibite, $10(Ca,Mg)O.5Al_2O_3.B_2O_3.6SiO_2$.
Silicomagnesiofluorite, $H_2Ca_4Mg_3Si_2O_7F_{10}$.
Grothine, Ca,Al, silicate.
Aloisite, Fe,Ca,Mg,Na, silicate.
Inesite, $H_2(Mn,Ca)_6Si_6O_{19}.3H_2O$.
Hillebrandite, $Ca_2SiO_4.H_2O$.
Crestmoreite, $4H_2CaSiO_4.3H_2O$.
Riversideite, $2CaSiO_5.H_2O$.
Lotrite,$3(Ca,Mg)O.2(Al,Fe)_2O_3.4SiO_2.2H_2O$
Okenite, $H_2CaSi_2O_5.H_2O$.
Gyrolite, $H_2Ca_2Si_3O_9.H_2O$.
APOPHYLLITE, $H_7KCa_4(SiO_3)_8.4\frac{1}{2}H_2O$.
Ptilolite, $(Ca,K_2,Na_2)Al_2Si_{10}O_{24}.5H_2O$.
Mordenite, $(Ca,K_2,Na_2)Al_2Si_{10}O_{24}.20H_2O$.
HEULANDITE, $H_4CaAl_2(SiO_3)_6.3H_2O$.
Brewsterite, $H_4(Sr,Ba,Ca)Al_2(SiO_3)_6.3H_2O$.
Epistilbite, $H_4CaAl_2(SiO_3)_6.3H_2O$.
Wellsite, $(Ba,Ca,K_2)Al_2Si_3O_{10}.3H_2O$.
Phillipsite, $(K_2,Ca)Al_2Si_4O_{12}.4\frac{1}{2}H_2O$.
Stilbite, $(Na_2,Ca)Al_2Si_6O_{16}.6H_2O$.
Flokite, $H_8(Ca,Na_2)Al_2Si_9O_{26}.2H_2O$.
Gismondite, $CaAl_2Si_2O_8.4H_2O$.
Laumontite, $H_4CaAl_2Si_4O_{14}.2H_2O$.
Laubanite, $Ca_2Al_2Si_5O_{15}.6H_2O$.
CHABAZITE, $(Ca,Na_2)Al_2Si_4O_{12}.6H_2O$.
Gmelinite, $(Na_2,Ca)Al_2Si_4O_{12}.6H_2O$.
Levynite, $CaAl_2Si_3O_{10}.5H_2O$.
Faujasite, $H_4Na_2CaAl_4Si_{10}O_{38}.18H_2O$.
Scolecite, $Ca(AlOH)_2(SiO_3)_3.2H_2O$.
Mesolite, $Na_2Al_2Si_3O_{10}.2H_2O+2[CaAl_2Si_3O_{10} 3H_2O]$.
Gonnardite, $(Ca,Na_2)_2Al_2Si_5O_{15}.5\frac{1}{2}H_2O$.
Thomsonite, $(Na_2,Ca)Al_2Si_2O_8.2\frac{1}{2}H_2O$.
Hydrothomsonite, $(H_2,Na_2,Ca)Al_2Si_2O_8.5H_2O$.
Arduinite, Ca,Na, zeolite.
Echellite, $(Ca,Na_2)O.2Al_2O_3.3SiO_2.4H_2O$.
Epidesmine, $(Na_2,Ca)Al_2Si_6O_{16}.6H_2O$.
Stellerite, $CaAl_2Si_7O_{18}.7H_2O$.
Erionite, $H_2CaK_2Na_2Al_2Si_6O_{17}.5H_2O$.
Bavenite, $Ca_3Al_2(SiO_3)_6.H_2O$.
Bityite, Hydrous, Ca,Al, silicate.
Margarite, $H_2CaAl_4Si_2O_{12}$.
Seybertite, $H_3(Mg,Ca)_5Al_5Si_2O_{18}$.
Xanthophyllite, $H_8(Mg,Ca)_{14}Al_{16}Si_5O_{52}$.
Griffithite, $4(Mg,Fe,Ca)O(Al,Fe)_2O_3.5SiO_2.7H_2O$.
Cenosite, $H_4Ca_2(Y,Er)_2CSi_4O_{17}$.
Plazolite, $3CaO.Al_2O_3.2(SiO_2,CO_2).2H_2O$.
Thaumasite, $CaSiO_3.CaCO_3.CaSO_4.15H_2O$.
Spurrite, $2Ca_2SiO_4.CaCO_3$.
Uranophane, $CaO.2UO_3.2SiO_2.6H_2O$.
Bakerite, Hydrous Ca boro-silicate.
TINANITE, $CaTiSiO_5$.
Molengraafite, Ca,Na, titano-silicate.
Keilhauite, Ca,Al,Fe,Y, titano-silicate.
Joaquinite, Ca,Fe, titano-silicate.
Perovskite, $CaTiO_3$.
Dysanalyte, Ca,Fe, titano-niobate.
Pyrochlore, Ca,Ce, niobate.
Koppite, Ca;Ce,niobate

Chalcolamprite, $\overset{II}{R}Nb_2O_6F_2.\overset{II}{R}SiO_3$.
Microlite, $Ca_2Ta_2O_7$.
Berzeliite, $(Ca,Mg,Mn,Na_2)_3As_2O_8$.
Graftonite, $(Fe,Mn,Ca)_3P_2O_8$.
Apatite, $Ca_4(CaF)(PO_4)_3$.
Fermorite, $(Ca,Sr)_4[Ca(OH,F)][(P,As)O_4]_3$.
Wilkeite, $3Ca_3(PO_4)_2.CaCO_3.3Ca_3[(SiO_4)(SO_4)].CaO$.
Svabite, Ca arsenate.
Spodiosite, $(CaF)CaPO_4$.
Adelite $(MgOH)CaAsO_4$.
Tilasite $(MgF)CaAsO_4$.
Herderite, $Ca[Be(F,OH)]PO_4$.
Ježekite, $Na_4CaAl(AlO)(F,OH)_4(PO_4)_2$.
Crandallite, $2CaO.4Al_2O_3.2P_2O_5.10H_2O$.
Lacroixite, $Na_4(Ca,Mn)_4Al_3(F,OH)_6P_3O_{16}.2H_2O$.
Calciovolborthite, $(Cu,Ca)_3V_2O_8.(Cu,Ca)(OH)_2$.
Tavistockite, $Ca_3P_2O_8.2Al(OH)_2$.
Cirrolite, $Ca_3Al(PO_4)_3.Al(OH)_3$.
Arseniosiderite, $Ca_3Fe(AsO_4)_3.3Fe(OH)_3$.
Retzian, Y,Mn,Ca, arsenate.
Arseniopleite, $(Mn,Ca)_9(Mn,Fe)_2(OH)_6(AsO_4)_6$.
Collophanite, $Ca_3P_2O_8.H_2O$.
Pyrophosphorite, $Mg_2P_2O_7.4(Ca_3P_2O_8.Ca_2P_2O_7)$.
Roselite, $(Ca,Co,Mg)_3As_2O_8.2H_2O$.
Brandite, $Ca_2MnAs_2O_8.2H_2O$.
Fairfieldite, $Ca_2MnP_2O_8.2H_2O$.
Messelite, $(Ca,Fe)_3P_2O_8.2\frac{1}{2}H_2O$.
Anapaite, $(Ca,Fe)_3P_2O_8.4H_2O$.

Picropharmacolite, $(Ca,Mg)As_2O_8.6H_2O$.
Churchite, Hydrous Ca,Ce, phosphate.
Fernandinite, $CaO.V_2O_4.5V_2O_5.14H_2O$.
Pascoite, $2CaO.3V_2O_5.11H_2O$.
Pintadoite, $2CaO.V_2O_5.9H_2O$.
Pharmacolite, $HCaAsO_4.2H_2O$.
Haidingerite, $HCaAsO_4.H_2O$.
Wapplerite, $HCaAsO_4.3\frac{1}{2}H_2O$.
Brushite, $HCaPO_4.2H_2O$.
Martinite, $H_2Ca_5(PO_4)_4.\frac{1}{2}H_2O$.
Hewettite
Metahewettite } $CaO.3V_2O_5.9H_2O$.
Isoclasite, $Ca_3P_2O_8.Ca(OH)_2.4H_2O$.
Conichalcite, $(Cu,Ca)_3As_2O_8.(Cu,Ca)(OH)_2.\frac{1}{2}H_2O$.
Volborthite, Cu,Ba,Ca, vanadate.
Mazapilite, $Ca_3Fe_2(AsO_4)_4.2FeO(OH).5H_2O$.
Yukonite, $(Ca_3,Fe_2''')(AsO_4)_2.2Fe(OH)_3.5H_2O$.
Calcioferrite, $Ca_3Fe_2(PO_4)_4.Fe(OH)_3.8H_2O$.
Borickite, $Ca_3Fe_2(PO_4)_4.12Fe(OH)_3.6H_2O$.
Egueiite, Hydrous Fe,Al,Ca, phosphate.
Goyazite, $Ca_3Al_{10}P_2O_{23}.9H_2O$.
Roschérite, $(Mn,Fe,Ca)_2Al(OH)(PO_4)_2.2H_2O$.
Autunite
Bassetite } $Ca(UO_2)_2P_2O_8.8H_2O$.
Uranospinite, $Ca(UO_2)_2As_2O_8.8H_2O$.
Tyuyamunite, $CaO.2UO_3.V_2O_5.4H_2O$.
Romeite, $CaSb_2O_4$.
Lewisite, $5CaO.2TiO_2.3Sb_2O_5$.
Mauzeliite, Pb,Ca, titano-antimonate.
Podolite, $3Ca_3(PO_4)_2.CaCO_3$.
Svanbergite, Hydrous Al,Ca, phosphate and sulphate.
Nitrocalcite, $Ca(NO_3)_2.nH_2O$.
Lautarite, $Ca(IO_3)_2$.
Dietzeite, Ca iodo-chromate.
Nordenskiöldine, $CaSn(BO_3)_2$.
Howlite, $H_5Ca_2B_5SiO_{14}$.
COLEMANITE, $Ca_2B_6O_{11}.5H_2O$.
Inyoite, $2CaO.3B_2O_3.13H_2O$.
Meyerhofferite, $2CaO.3B_2O_3.7H_2O$.
Ulexite, $NaCaB_5O_9.8H_2O$.
Bechilite, $CaB_4O_7.4H_2O$.
Hydroboracite, $CaMgB_6O_{11}.6H_2O$.
GLAUBERITE, $Na_2SO_4.CaSO_4$.
Anhydrite
Bassanite } $CaSO_4$.
Gypsum, $CaSO_4.2H_2O$.
Syngenite, $CaSO_4.K_2SO_4.H_2O$.
Polyhalite, $2CaSO_4.MgSO_4.K_2SO_4.2H_2O$.
Ettringite, $6CaO.Al_2O_3.3SO_3.33H_2O$.
Uranopilite, $CaU_8S_2O_{31}.25H_2O$.
SCHEELITE, $CaWO_4$.
Powellite, $Ca(Mo,W)O_4$.
Whewellite, $CaC_2O_4.H_2O$.

CERIUM EARTHS

Tysonite, $(Ce,La,Di)F_3$.
Fluocerite, $(Ce,La,Di)_2OF_4$.
Yttrocerite, $(Y,Er,Ce)F_3.5CaF_2.H_2O$.
Parisite, $[(Ce,La,Di)F]_2.CaCO_3$.
Bastnäsite, $(CeF)CO_3$.
Ancylite, $4Ce(OH)CO_3.3SrCO_3.3H_2O$.
Ambatoarinite, Rare earths, Sr, carbonate.
Lanthanite, $La_2(CO_3)_3.9H_2O$.
Melanocerite
Caryocerite } Ca,Ce,Y, fluo-silicates.
Steenstrupine
Tritomite, Th,Ce,Y,Ca, fluo-silicate.
Mackintoshite, U,Th,Ce, silicate.
Allanite, Ca,Fe,Ce,Al, silicate.
Cerite, Ce, etc., silicate.
Beckelite, $Ca_3(Ce,La,Di)_4Si_3O_{15}$.
Hellandite, Ce, etc., Al,Mn,Ca, silicate.
Bazzite, Sc., etc., silicate.
Britholite, Ce, etc., silicate and phosphate.
Erikite, Ce, etc., silicate and phosphate.
Tscheffkinite, Ce,Fe, titano-silicate.
Johnstrupite
Mosandrite } Ce, etc., titano-silicates.
Rinkite
Knopite, Ca,Ce, titanate.
Pyrochlore, Ca,Ce, niobate.
Chalcolamprite, $\overset{\text{II}}{R}''Nb_2O_6F_2.\overset{\text{II}}{R}''SiO_3$.
Koppite, Ca,Ce, niobate.
Fergusonite, Y,Er,Ce,U, niobate.
Sipylite, Er,Ce, niobate.
Yttrotantalite, Fe,Ca,Y,Er,Ce, tantalate.
Samarskite, Fe,Ca,U,Ce,Y. niobate.
Aeschynite, Ce, niobate-titanate.
Polymignite, Ce, Fe, Ca, niobate-titanate.
Euxenite
Polycrase } Y,Ce,U, niobate-titanates.
Blomstrandine-Priorite
MONAZITE, $(Ce,La,Di)PO_4$.
Florencite, Ce,Al, phosphate.
Rhabdophanite, Hydrous Ce,Y, phosphate.
Churchite, Hydrous Ce,Ca, phosphate.

CHROMIUM

Daubréelite, $FeS.Cr_2S_3$.
Chromite, $FeO.Cr_2O_3$.
Stichtite, $2MgCO_3.5Mg(OH)_2.2Cr(OH)_3$.
Uvarovite, $Ca_3Cr_2(SiO_4)_3$.
Furnacite, Pb,Cu, chrom-arsenate.
Dietzite, Ca iodo-chromate.
CROCOITE, $PbCrO_4$.
Phœnicochroite, $3PbO.2CrO_3$.
Vauquelinite, $2(Pb,Cu)CrO_4.(Pb,Cu)_3P_2O_8$.
Bellite, Pb, arseno-chromate.
Knoxvillite, Hydrous Fe,Al,Cr, sulphate.
Redingtonite, Hydrous Cr sulphate.

COBALT

Sychnodymite, $(Co,Cu)_4S_5$.
LINNÆITE, Co_3S_4.
Carrollite, $CuCo_2S_4$.
Badenite, $(Co,Ni,Fe)_2(As,Bi)_3$.
Cobaltnickelpyrite, $(Co,Ni,Fe)S_2$.
SMALTITE, $CoAs_2$.
COBALTITE, $CoAsS$.
Willyamite, $CoS_2.NiS_2.CoSb_2.NiSb_2$.
Villamaninite, Cu,Ni,Co,Fe, sulphide.

Skutterudite, $CoAs_3$.
Safflorite, $CoAs_2$.
Glaucodot, $(Co,Fe)AsS$.
Sphærocobaltite, $CoCO_3$.
Remingtonite, Hydrous, carbonate.
Roselite, $(Ca,Co,Mg)_3As_2O_8.2H_2O$.
Erythrite, $Co_3As_2O_8.8H_2O$.
Forbesite, $H_2(Ni,Co)_2As_2O_8.8H_2O$.
Bieberite, $CoSO_4.7H_2O$.

COPPER

Native Copper, Cu.
Horsfordite, Cu_6Sb.
Domeykite, Cu_3As.
Mohawkite, Cu_3As.
Algodonite, Cu_6As.
Whitneyite, Cu_9As.
Cocinerite, Cu_4AgS.
Rickardite, Cu_4Te_3.
Berzelianite, Cu_2Se.
Eucairite, $Cu_2Se.Ag_2Se$.
Zorgite, Pb,Cu, selenide.
Crookesite, Cu,Tl, selenide.
Umangite, $CuSe.Cu_2Se$.
Chalcocite, Cu_2S.
Stromeyrite, $(Ag,Cu)_2S$.
Chalmersite, $Cu_2S.Fe_4S_5$.
COVELLITE, CuS.
Sychnodymite, $(Co,Cu)_4S_5$.
Bornite, Cu_5FeS_4.
Carrollite, $CuS.Co_2S_3$.
Chalcopyrite, $CuFeS_2$.
Villamaninite, Cu,Ni,Co,Fe, sulphide.
Eichbergite, $(Cu,Fe)_2S.3(Bi,Sb)_2S_3$.
Histrixite, $5CuFeS_2.2Sb_2S_3.7Bi_2S_3$.
Cuprobismutite, $3Cu_2S.4Bi_2S_3$.
Emplectite, $Cu_2S.Bi_2S_3$.
Chalcostibite, $Cu_2S.Sb_2S_3$.
Hutchinsonite, $(Tl,Ag,Cu)_2S.As_2S_3 + PbS.As_2S_3$?
Klaprotholite, $3Cu_2S.Bi_2S_3$.
Bournonite, $3(Pb,Cu_2)S.Sb_2S_3$.
Seligmannite, $3(Pb,Cu_2)S.As_2S_3$.
Aikinite, $2PbS.Cu_2S.Bi_2S_3$.
Wittichenite, $3Cu_2S.Bi_2S_3$.
Stylotypite, $3(Cu_2,Ag_2,Fe)S.Sb_2S_3$.
Lengenbachite, $7[Pb,(Ag,Cu)_2]S.2As_2S_3$.
Falkenhaynite, $3Cu_2S.Sb_2S_3$.
Tetrahedrite, $4Cu_2S.Sb_2S_3$.
TENNANTITE, $4Cu_2S.As_2S_3$.
Goldfieldite, $5Cu_2S.(Sb,As,Bi)_2(S.Te)_3$.
Enargite, $3Cu_2S.As_2S_5$.
Famatinite, $3Cu_2S.Sb_2S_5$.
Sulvanite, $3Cu_2S.V_2S_5$.
Epigenite, $4Cu_2S.3FeS.As_2S_5$.
STANNITE, $Cu_2S.FeS.SnS_2$.
Nantokite, $CuCl$.
Marshite, CuI.
Miersite, $4AgI.CuI$.
ATACAMITE, $CuCl_2.3Cu(OH)_2$.
Percylite, $PbCl_2.CuO.H_2O$.
Boleite. $9PbCl_2.8CuO.3AgCl.9H_2O$.
Pseudoboleite, $5PbCl_2.4CuO.6H_2O$.
Cumengite, $4PbCl_2.4CuO.5H_2O$.
Tallingite, Hydrous Cu chloride.
Cuprite, Cu_2O.
Tenorite, Paramelaconite, CuO.
Crednerite, $3CuO.2Zn_2O_3$.
Rosasite, $2CuO.3CuCO_3.5ZnCO_3$?
Malachite, $CuCO_3.Cu(OH)_2$.
Azurite, $2CuCO_3.Cu(OH)_2$.
Aurichalcite, $2(Zn,Cu)CO_3.3(Zn,Cu)(OH)_2$.
Voglite, Hydrous U,Ca,Cu, carbonate.
Dioptase, H_2CuSiO_4.
Planchéite, $H_4Cu_7(Cu.OH)_8(SiO_3)_{13}$.
CHRYSOCOLLA, $CuSiO_3.2H_2O$.
Shattuckite, $2CuSiO_3.H_2O$.
Bisbeeite, $CuSiO_3.H_2O$
Olivenite, $Cu_2(OH)AsO_4$.
Libethenite, $Cu_2(OH)PO_4$.
Calciovolborthite, $(Cu,Ca)_3V_2O_8.(Cu,Ca)(OH)_2$.
Turanite, $5CuO.V_2O_5.2H_2O$.
$\left.\begin{array}{l}\text{Psittacinite}\\ \text{Mottramite}\end{array}\right\}$ Pb,Cu, vanadates.
Furncite, Pb,Cu, chrom-arsenate.
Tsumebite, Pb,Cu, phosphate.
Clinoclasite, $Cu_3As_2O_8.3Cu(OH)_2$.
Erinite, $Cu_3As_2O_8.2Cu(OH)_2$.
Dihydrite, $Cu_3P_2O_8.2Cu(OH)_2$.
Pseudomalachite, $Cu_3P_2O_8.3Cu(OH)_2$.
Trichalcite, $Cu_3As_2O_8.5H_2O$.
Rosiérésite, Hydrous Al,Pb,Cu, phosphate.
Eucroite, $Cu_3As_2O_8.Cu(OH)_2.6H_2O$.
Conichalcite, $(Cu,Ca)_3As_2O_8.(Cu,Ca)(OH)_2.\frac{1}{2}H_2O$.
Bayldonite, $(Pb,Cu)_3As_2O_8.(Pb,Cu)(OH)_2.H_2O$.
Tagilite, $Cu_3P_2O_8.Cu(OH)_2.2H_2O$.
Leucochalcite, $Cu_3As_2O_8.Cu(OH)_2.2H_2O$.
Barthite, $3ZnO.CuO.3As_2O_5.2H_2O$.
Volborthite, Hydrous, Cu,Ba,Ca, vanadate.
Cornwallite, $Cu_3As_2O_8.2Cu(OH)_2.H_2O$.
Tyrolite, $Cu_3As_2O_8.2Cu(OH)_2.7H_2O$.
Chalcophyllite, $7CuO.As_2O_5.14H_2O$.
Veszelyite, Hydrous Cu,Zn, phospho-arsenate.
Turquois, $CuO.3Al_2O_3.2P_2O_5.9H_2O$.
Liroconite,$Cu_6Al(AsO_4)_5.3CuAl(OH)_5.20H_2O$
Chenevixite, $Cu_2(FeO)_2As_2O_8.3H_2O$.
Henwoodite, Al,Cu, hydrous phosphate.
Ceruleite, $CuO.2Al_2O_3.As_2O_5.8H_2O$.
Chalcosiderite, $CuO.2Fe_2O_3.2P_2O_5.8H_2O$.
Torbernite, $Cu(UO_2)_2P_2O_8.8H_2O$.
Zeunerite, $Cu(UO_2)_2As_2O_8.8H_2O$.
Mixite, Hydrous Cu,Bi, arsenate.
Trippkeite, Cu, arsenite.
Lindackerite, $3NiO.6CuO.SO_3.2As_2O_5.7H_2O$.
Gerhardtite, $Cu(NO_3)_2.3Cu(OH)_2$.
Hydrocyanite, $CuSO_4$.
Vauquelinite, $2(Pb,Cu)CrO_4.(Pb,Cu)_3P_2O_8$.
Connellite, $CuSO_4.2CuCl_2.19Cu(OH)_2.H_2O$.
Spangolite, $Cu_6AlClSO_{10}.9H_2O$.
BROCHANTITE, $CuSO_4.3Cu(OH)_2$.
Dolerophanite, Cu_2SO_5.
Caledonite, $2(Pb,Cu)O.SO_3.H_2O$.

Linarite, $(Pb,Cu)SO_4.(Pb,Cu)(OH)_2$.
Anthrite, $CuSO_4.2Cu(OH)_2$.
Pisanite, $(Fe,Cu)SO_4.7H_2O$.
Boothite, $CuSO_4.7H_2O$.
Cupromagnesite, $(Cu,Mg)SO_4.7H_2O$.
CHALCANTHITE, $CuSO_4.5H_2O$.
Kröhnkite, $CuSO_4.Na_2SO_4.2H_2O$.
Natrochalcite, $Cu_4(OH)_2(SO_4)_2.Na_2SO_4.2H_2O$
Phillipite, $CuSO_4.Fe_2(SO_4)_3.nH_2O$.
Langite, $CuSO_4.3Cu(OH)_2.H_2O$.
Herrengrundite, $2(CuOH)_2SO_4.Cu(OH)_2$.
Vernadskite, $3CuSO_4.Cu(OH)_2.4H_2O$.
Kamarezite, Hydrous basic Cu sulphate.
Cyanotrichite, $4CuO.Al_2O_3.SO_3.8H_2O$.
Serpierite, Hydrous basic Cu,Zn, sulphate.
Beaverite, $CuO.PbO.Fe_2O_3.2SO_3.4H_2O$.
Johannite, Hydrous Cu,U, sulphate.
Gilpinite, $(Cu,Fe,Na_2)O.UO_3.SO_3.4H_2O$.
Chalcomenite, $CuSeO_3.2H_2O$.
Cuprotiungstite, $CuWO_4$.

GOLD

Native Gold, Au.
Petzite, $(Ag,Au)_2Te$.
SYLVANITE, $(Au,Ag)Te_2$.
Krennerite, $(Au,Ag)Te_2$.
CALAVERITE, $AuTe_2$.
Muthmannite, $(Ag,Au)Te$.
Nagyagite, Au,Pb, sulpho-telluride.

IRON

Native Iron, Fe.
Awaruite, $FeNi_2$.
Josephinite, $FeNi_3$.
Chalmersite, $Cu_2S.Fe_4S_5$.
Sternbergite, $Ag_2S.Fe_4S_5$.
Pentlandite, $(Fe,Ni)S$.
Pyrrhotite, FeS.
Troilite, FeS.
Daubréelite, $FeS.Cr_2S_3$.
Badenite, $(Co,Ni,Fe)_2(As,Bi)_3$.
Chalcopyrite, $CuFeS_2$.
Pyrite, FeS_2.
Bravoite, $(Fe,Ni)S_2$.
Cobaltnickelpyrite, $(Fe,Co,Ni)S_2$.
Arsenoferrite, $FeAs_2$.
Marcasite, FeS_2.
Löllingite, $FeAs_2$.
Arsenopyrite, FeAsS.
Eichbergite, $(Cu,Fe)_2S.3(Bi,Sb)_2S_3$.
Histrixite, $5CuFeS_2.2Sb_2S_3.7Bi_2S_3$.
Berthierite, $FeS.Sb_2S_3$.
Stylotypite, $3(Cu_2,Ag_2,Fe)S.Sb_2S_3$.
Molysite, $FeCl_3$.
Lawrencite, $FeCl_2$.
Rinneite, $FeCl_2.3KCl.NaCl$.
Kremersite, $KCl_2.NH_4Cl.FeCl_2.H_2O$.
Erythrosiderite, $2KCl.FeCl_3.H_2O$.
Hematite, Fe_2O_3.
ILMENITE, $FeTiO_3$.
Senaite, $(Fe,Mn,Pb)O.TiO_2$.
Arizonite, $Fe_2O_3.3TiO_2$.
Sitaparite, $9Mn_2O_3.4Fe_2O_3.MnO_2.3CaO$.
Vredenburgite, $3Mn_3O_4.2Fe_2O_3$.
Hercynite, $FeO.Al_2O_3$.
Magnetite, $FeO.Fe_2O_3$.
FRANKLINITE, $(Fe,Zn,Mn)O.(Fe,Mn)_2O_3$.
Magnesioferrite, $MgO.Fe_2O_3$.
Jacobsite, $(Mn,Mg)O.(Fe,Mn)_2O_3$.
Chromite, $FeO.Cr_2O_3$.
Pseudobrookite, $Fe_4(TiO_4)_3$.
Bixbyite, $FeO.MnO_2$.
Göthite, $Fe_2O_3.H_2O$.
Lepidocrocite, $Fe_2O_3.H_2O$.
Limonite, $2Fe_2O_3.3H_2O$.
Turgite, $2Fe_2O_3.H_2O$.
Hydrogöthite, $3Fe_2O_3.4H_2O$.
Xanthosiderite, $Fe_2O_3.2H_2O$.
Esmeraldaite, $Fe_2O_3.4H_2O$.
Pyroaurite, $Fe(OH)_3.3Mg(OH)_2.3H_2O$.
Skemmatite, $3MnO_2.2Fe_2O_3.6H_2O$.
Beldongrite, $6Mn_2O_3.Fe_2O_3.8H_2O$.
Ankerite, $2CaCO_3.MgCO_3.FeCO_3$.
Mesitite, $2MgCO_3.FeCO_3$.
Pistomesite, $MgCO_3.FeCO_3$.
Siderite, $FeCO_3$.
Brugnatellite, $MgCO_3.5Mg(OH)_2.Fe(OH)_3.4H_2O$.
HYPERSTHENE, $(Fe,Mg)SiO_3$.
ACMITE, $NaFe(SiO_3)_2$.
Pyroxmangite, Mn,Fe, pyroxene.
Babingtonite, $(Ca,Fe,Mn)SiO_3$, with $Fe_2(SiO_3)_3$.
ANTHOPHYLLITE, $(Mg,Fe)SiO_3$.
GLAUCOPHANE, $NaAl(SiO_3)_2.(Fe,Mg)SiO_3$.
RIEBECKITE, $2NaFe(SiO_3)_2.FeSiO_3$.
CROCIDOLITE, $NaFe(SiO_3)_2.FeSiO_3$.
ARFVEDSONITE, Na,Ca,Fe, silicate.
Ænigmatite, Fe,Na,Ti-silicate.
Weinbergerite, $NaAlSiO_4.3FeSiO_3$.
Astrolite, $(Na,K)_2Fe(Al,Fe)_2(SiO_3)_5.H_2O$?
Iolite, $H_2(Mg,Fe)_4Al_8Si_{10}O_{37}$.
Taramellite, $Ba_4Fe''Fe_4'''Si_{10}O_{31}$.
Helvite, $(Be,Mn,Fe)_7Si_3O_{12}S$.
Almandite, $Fe_3Al_2(SiO_4)_3$.
Andradite, $Ca_3Fe_2(SiO_4)_3$.
Partschinite, $(Mn,Fe)_3Al_2Si_3O_{12}$.
Fayalite, Fe_2SiO_4.
Knebelite, $(Fe,Mn)_2SiO_4$.
Pyrosmalite, $H_7((Fe,Mn)Cl)(Fe,Mn)_4Si_4O_{16}$.
Homilite, $(Ca,Fe)_3B_2Si_2O_{10}$.
Allanite, $(Ca,Fe)_2(AlOH)(Al,Ce,Fe)_2(SiO_4)_3$.
ILVAITE, $CaFe_2(FeOH)(SiO_4)_2$.
Melanotekite, $3PbO.2Fe_2O_3.3SiO_2$.
Angaralite, $2(Ca,Mg)O.5(Al,Fe)_2O_3.6SiO_2$.
STAUROLITE, $(AlO)_4(AlOH)Fe(SiO_4)_2$.
Grandidierite, Al,Fe,Mg, silicate.
Aloisite, Fe,Ca,Mg,Na, silicate.
Pöchite, $H_{16}Fe_8Mn_2Si_3O_{29}$.
Lotrite, $3(Ca,Mg)O.2(Al,Fe)_2O_3.4SiO_2.2H_2O$.
Zinnwaldite, Li-Fe mica.
Biotite, Mg-Fe mica.
Lepidomelane, Iron mica.
Chloritoid, $H_2(Fe,Mg)Al_2SiO_7$.

Prochlorite, Fe,Mg,chlorite.
Moravite, $2FeO.2(Al,Fe)_2O_3.7SiO_2.2H_2O$.
Cronstedtite, $4FeO.2Fe_2O_3.3SiO_2.4H_2O$.
Thuringite, $8FeO.4(Al,Fe)_2O_3.6SiO_2.9H_2O$.
Brunsvigite, $9(Fe,Mg)O.2Al_2O_3.6SiO_2.8H_2O$.
Griffithite, $4(Mg,Fe,Ca)O.(Al,Fe)_2O_3.5SiO_2.7H_2O$.
Chamosite, Fe,Mg, silicate.
Stilpnomelane }
Minguétite } Fe silicates.
Strigovite, $H_4Fe_2(Al,Fe)_2Si_2O_{11}$.
Spodiophyllite, $(Na_2,K_2)_2(Mg,Fe)_3(Fe,Al)_2(SiO_3)_8$.
Celadonite, Fe,Mg,K, silicate.
Glauconite, Hydrous Fe,K, silicate.
Pholidolite, $K_2O.12(Fe,Mg)O.Al_2O_3.13SiO_2.5H_2O$.
Faratsihite, $(Al,Fe)_2O_3.2SiO_2.2H_2O$.
Melite, $2(Al,Fe)_2O_3.SiO_2.8H_2O$.
Chloropal, $H_6Fe_2(SiO_4)_3.2H_2O$.
Müllerite, $Fe_2Si_3O_9.2H_2O$.
Hisingerite }
Morencite } Hydrous ferric silicates.
Astrophyllite, Na, K, Fe, Mn, titano-silicate.
Narsarsukite, Fe,Na, titano-silicate.
Neptunite, Fe,Mn,Na,K, titano-silicate.
Joaquinite, Ca,Fe, titano-silicate.
Dysanalyte, Ca,Fe, titano-niobate.
Geikielite, $(Mg,Fe)TiO_3$.
Delorenzite, Fe,U,Y, titanate.
Neotantalite, Fe tantalate.
Columbite, Tantalite, $(Fe,Mn)(Nb,Ta)_2O_6$.
Tapiolite, $Fe(Ta,Nb)_2O_6$.
Yttrotantalite, Fe,Ca,Y,Er,Ce, tantalate.
Samarskite, Fe,U,Y, etc., niobate-tantalate.
Hielmite, Y,Fe,Mn,Ca, stanno-tantalate.
Monimolite, Pb,Fe, antimonate.
Triphylite, $Li(Fe,Mn)PO_4$.
Graftonite, $(Fe,Mn,Ca)_3P_2O_8$.
Triplite, $(RF)RPO_4$; R = Fe,Mn.
Triploidite $(ROH)RPO_4$; R = Fe,Mn.
Dufrenite, $FePO_4.Fe(OH)_3$.
Lazulite, $2AlPO_4.(Fe,Mg)(OH)_2$.
Arseniosiderite, $Ca_3Fe(AsO_4)_3.3Fe(OH)_3$.
Dickinsonite }
Fillowite } Hydrous Mn,Fe,Na, phosphate.
Messelite $(Ca,Fe)_3P_2O_8.2\frac{1}{2}H_2O$.
Anapaite, $(Ca,Fe)_3P_2O_8.4H_2O$.
Vivianite, $Fe_3P_2O_8.8H_2O$.
Symplesite, $Fe_3As_2O_8.8H_2O$.
Scorodite, $FeAsO_4.2H_2O$.
Vilateite, Hydrous Fe, Mn, phosphate.
Purpurite, $2(Fe,Mn)PO_4.H_2O$.
Strengite, $FePO_4.2H_2O$.
Phosphosiderite, $2FePO_4.3\frac{1}{2}H_2O$.
Barrandite, $(Al,Fe)PO_4.2H_2O$.
Koninckite, $FePO_4.3H_2O$.
Sicklerite, $Fe_2O_3.6MnO.4P_2O_5.3(Li,H)_2O$.
Salmonsite, $Fe_2O_3.9MnO.4P_2O_5.14H_2O$.
Liskeardite, $(Al,Fe)AsO_4.2(Al,Fe)(OH)_3.5H_2O$.
Pharmacosiderite, $6FeAsO_4.2Fe(OH)_3.12H_2O$.
Ludlamite, $2Fe_3P_2O_8.Fe(OH)_2.8H_2O$.
Cacoxenite, $FePO_4.Fe(OH)_3.4\frac{1}{2}H_2O$.
Beraunite, $2FePO_4.Fe(OH)_3.2\frac{1}{2}H_2O$.
Childrenite, $2AlPO_4.2Fe(OH)_2.2H_2O$.
Mazapilite, $Ca_3Fe_2(AsO_4)_4.2FeO(OH).5H_2O$.
Yukonite, $(Ca_3,Fe_2''')(AsO_4)_2.2Fe(OH)_3.5H_2O$.
Calcioferrite, $Ca_3Fe_2(PO_4)_4.Fe(OH)_3.8H_2O$.
Borickite, $Ca_3Fe_2(PO_4)_4.12Fe(OH)_3.6H_2O$.
Egueiite, Hydrous Fe,Al,Ca, phosphate.
Richelite, $4FeP_2O_8.Fe_2OF_2(OH)_2.36H_2O$.
Chenevixite, $Cu_2(FeO)_2As_2O_8.3H_2O$.
Chalcosiderite, $CuO.3Fe_2O_3.2P_2O_5.8H_2O$.
Roschérite, $(Mn,Fe,Ca)_2Al(OH)(PO_4)_2.2H_2O$.
Tripuhyite, $2FeO.Sb_2O_5$.
Flajolotite, $4FeSbO_4.3H_2O$.
Catoptrite, $14(Mn,Fe)O.2(Al,Fe)_2O_3.2SiO_2.Sb_2O_5$.
Derbylite, Fe antimo-titanate.
Diadochite, Hydrous Fe phosphate and sulphate.
Pitticite, Hydrous Fe arsenate and sulphate.
Beudantite, $3Fe_2O_3.2PbO.2SO_3.As_2O_5.6H_2O$.
Hinsdalite, $3Fe_2O_3.2PbO.2SO_3.P_2O_5.6H_2O$.
Lossenite, Hydrous Fe,Pb, arsenate and sulphate.
Ludwigite, $3MgO.B_2O_3.FeO.Fe_2O_3$.
Vonsenite, $3(Fe,Mg)O.B_2O_3.FeO.Fe_2O_3$.
Magnesioludwigite, $3MgO.B_2O_3.MgO.Fe_2O_3$.
Warwickite, $(Mg,Fe)_3TiB_2O_8$.
Lagonite, $Fe_2O_3.3B_2O_3.3H_2O$.
Hulsite, $12(Fe,Mg)O.2Fe_2O_3.1SnO_2.3B_2O_3$.
Millosevichite, $(Fe,Al)_2(SO_4)_3$.
Szomolnokite, $FeSO_4.H_2O$.
Ilesite, $(Mn,Zn,Fe)SO_4.4H_2O$.
Melanterite, $FeSO_4.7H_2O$.
Pisanite, $(Fe,Cu)SO_4.7H_2O$.
Halotrichite, $FeSO_4.Al_2(SO_4)_3.24H_2O$.
Bilinite, $FeSO_4.Fe_2(SO_4)_3.24H_2O$.
Dietrichite, $(Zn,Fe,Mn)SO_4.Al_2(SO_4)_3.22H_2O$.
Coquimbite, $Fe_2(SO_4)_3.9H_2O$.
Quenstedtite, $Fe_2(SO_4)_3.10H_2O$.
Ihlëite, $Fe_2(SO_4)_3.12H_2O$.
Phillipite, $CuSO_4.Fe_2(SO_4)_3.nH_2O$.
Ferronatrite, $3Na_2SO_4.Fe_2(SO_4)_3.6H_2O$.
Römerite, $FeSO_4.Fe_2(SO_4)_3.14H_2O$.
Beaverite, $CuO.PbO.Fe_2O_3.2SO_3.4H_2O$.
Vegasite, $PbO.3Fe_2O_3.3SO_3.6H_2O$.
Copiapite, $2Fe_2O_3.5SO_3.18H_2O$.
Castanite, $Fe_2O_3.2SO_3.8H_2O$.
Utahite, $3Fe_2O_3.2SO_3.7H_2O$.
Amaranthite, $Fe_2O_3.2SO_3.7H_2O$.
Fibroferrite, $Fe_2O_3.2SO_3.10H_2O$.
Raimondite, $2Fe_2O_3.3SO_3.7H_2O$.
Carphosiderite, $3Fe_2O_3.4SO_3.7H_2O$.
Planoferrite, $Fe_2O_3.SO_3.15H_2O$.
Glockerite, $2Fe_2O_3.SO_3.6H_2O$.
Knoxvillite, Hydrous Fe,Al,Cr, sulphate.

Cyprusite, $7Fe_2O_3.Al_2O_3.10SO_3.14H_2O$.
Botryogen, $MgO.FeO.Fe_2O_3.4SO_3.18H_2O$.
Sideronatrite, $2Na_2O.Fe_2O_3.4SO_3.7H_2O$.
Voltaite, $3(K_2,Fe)O.2(Al,Fe)_2O_3.6SO_3.9H_2O$.
Metavoltine, $5(K_2,Na_2,Fe)O.3Fe_2O_3.12SO_3.18H_2O$.
Jarosite, $K_2Fe_6(OH)_2(SO_4)_4$.
Natrojarosite, $Na_2Fe_6(OH)_{12}(SO_4)_4$.
Plumbojarosite, $PbFe_6(OH)_{12}(SO_4)_4$.
Quetenite, $MgO.Fe_2O_3.3SO_3.13H_2O$.
Rhomboclase, $Fe_2O_3.4SO_3.9H_2O$.
Emmonsite, Hydrous Fe tellurate.
Durdenite, $Fe_2(TeO_3)_3.4H_2O$.
WOLFRAMITE, $(Fe,Mn)WO_4$.
Reinite, $FeWO_4$.
Ferritungstite, $Fe_2O_3.WO_3.6H_2O$.
Humboltine, $FeC_2O_4.2H_2O$.

LEAD

Native Lead, Pb
Galena, PbS.
Altaite, Pb,Te.
Clausthalite, PbSe.
Naumannite, $(Ag_2,Pb)Se$.
Zorgite, Pb,Cu, selenide.
Chiviatite, $2PbS.3Bi_2S_3$.
Rezbanyite, $4PbS.5Bi_2S_3$.
Zinkenite, $PbS.Sb_2S_3$.
Andorite, $Ag_2S.2PbS.3Sb_2S_3$.
Sartorite, $PbS.As_2S_3$.
Platynite, $PbS.Bi_2Se_3$.
Galenobismutite, $PbS.Bi_2S_3$.
Hutchinsonite, $(Tl,Ag,Cu)_2S.As_2S_3 + PbS.As_2S_3$?
Baumhauerite, $4PbS.3As_2S_3$.
Schirmerite, $3(Ag_2,Pb)S.2Bi_2S_3$.
Rathite, $3PbS.2As_2S_3$.
Jamesonite, $2PbS.Sb_2S_3$.
Dufrenoysite, $2PbS.As_2S_3$.
Cosalite, $2PbS.Bi_2S_3$.
Kobellite, $2PbS.(Bi,Sb)_2S_3$.
Plagionite, Heteromorphite, Semseyite, Pb, Sb, sulphides.
Freieslebenite, $5(Pb,Ag_2)S.2Sb_2S_3$.
Diaphorite, $5(Pb,Ag_2)S.2Sb_2S_3$.
Boulangerite, $5PbS.2Sb_2S_3$.
Mullanite, $5PbS.2Sb_2S_3$.
Bournonite, $3(Pb,Cu_2)S.Sb_2S_3$.
Seligmanite, $3(Pb,Cu_2)S.As_2S_3$.
Aikinite, $2PbS.Cu_2S.Bi_2S_3$.
Lillianite, $3PbS.(Bi,Sb)_2S_3$.
Guitermanite, $3PbS.As_2S_3$.
Lengenbachite, $7[Pb,(Ag,Cu)_2]S.2As_2S_3$.
Jordanite, $4PbS.As_2S_3$.
Meneghinite, $4PbS.Sb_2S_3$
Geocronite, $5PbS.Sb_2S_3$.
Beegerite, $6PbS.Bi_2S_3$.
Epiboulangerite, $3PbS.Sb_2S_3$.
Teallite, $PbSnS_2$.
Franckeite, $Pb_5Sn_3FeSb_2S_{14}$.
Cylindrite, $Pb_3Sn_4FeSb_2S_{14}$.
Cotunnite, $PbCl_2$.
Percylite, $PbCl_2.CuO.H_2O$.
Boleite, $9PbCl_2.8CuO.3AgCl.9H_2O$.
Pseudo-boleite, $5PbCl_2.4CuO.6H_2O$.
Cumengite, $4PbCl_2.4CuO.5H_2O$.
Matlockite, $PbCl_2.PbO$.
Mendipite, $PbCl_2.2PbO$.
Lorettoite, $PbCl_2.6PbO$.
Laurionite, $PbCl_2.Pb(OH)_2$.
Penfieldite, $2PbCl_2.PbO$.
Daviesite, Pb oxychloride.
Schwartzenbergite, $Pb(I,Cl)_2.2PbO$.
Massicot, PbO.
Senaite, $(Fe,Mn,Pb)O.TiO_2$.
Coronadite, $(Mn,Pb)Mn_3O_7$.
Minium, $2PbO.PbO_2$.
Plattnerite, PbO_2.
Cerussite, $PbCO_3$.
PHOSGENITE, $PbCO_3.PbCl_2$.
Hydrocerussite, $2PbCO_3.Pb(OH)_2$.
Dundasite, $Pb(AlO)_2(CO_3)_2$.
Alamosite, $PbSiO_3$.
Barysilite, $Pb_3Si_2O_7$.
Molybdophyllite, $(Pb,Mg)SiO_4.H_2O$.
Ganomalite, $Pb_4(PbOH)_2Ca_4(Si_2O_7)_3$.
Nasonite, $Pb_4(PbCl)_2Ca_4(Si_2O_7)_3$.
Margarosanite, $Pb(Ca,Mn)_2(SiO_3)_3$.
Hyalotekite, $(Pb,Ba,Ca)B_2(SiO_3)_{12}$.
Roeblingite, $5(H_2CaSiO_4).2(CaPbSO_4)$
Hancockite, Pb,Mn,Ca,Al, etc., silicate.
Kentrolite, $3PbO.2Mn_2O_3.3SiO_2$.
Melanotekite, $3PbO.2Fe_2O_3.3SiO_2$.
Plumboniobite, Y,U,Pb,Fe, niobate
Monimolite, Pb,Fe, antimonate.
Carminite, $Pb_3As_2O_8.10FeAsO_4$.
Georgiadésite, $Pb_3(AsO_4)_2.3PbCl_2$.
PYROMORPHITE, $Pb_4(PbCl)(PO_4)_3$.
Mimetite, $Pb_4(PbCl)(AsO_4)_3$.
Vanadinite, $Pb_4(PbCl)(VO_4)_3$.
Trigonite, $Pb_3MnH(AsO_3)_3$.
Plumbogummite, Pb,Al, phosphate.
Descloizite, $(Pb,Zn)_2(OH)VO_4$.
Pyrobelonite, $4PbO.7MnO.2V_2O_5.3H_2O$.
Dechenite, PbV_2O_6.
$\left.\begin{array}{l}\text{Psittacinite}\\ \text{Mottramite}\end{array}\right\}$ Pb,Cu, vanadates.
Furnacite, Pb,Cu, chrom-arsenate.
Tsumebite, Pb,Cu, phosphate.
Rosiérésite, Hydrous Al,Pb,Cu, phosphate.
Ferrazite, $3(Ba,Pb)O.2P_2O_5.8H_2O$.
Bayldonite, $(Pb,Cu)_3As_2O_8.(Pb,Cu)(OH)_2.H_2O$.
Hügelite, Hydrous Pb,Zn, vanadate.
Bindheimite, Hydrous Pb antimonate.
Nadorite, $PbClSbO_2$.
Ecdemite, $Pb_4As_2O_7.2PbCl_2$.
Ochrolite, $Pb_4Sb_2O_7.2PbCl_2$.
Mauzeliite, Pb,Ca,titano-antimonate.
Beudantite, $3Fe_2O_3.2PbO.2SO_3.As_2O_5.6H_2O$.
Hinsdalite, $3Fe_2O_3.2PbO.2SO_3.P_2O_5.6H_2O$.
Lossenite, Hydrous Fe, Pb, arsenate and sulphate.
Anglesite, $PbSO_4$.
CROCOITE, $PbCrO_4$

Phœnicochroite, $3PbO.2CrO_3$.
Vauquelinite, $2(Pb,Cu)CrO_4.(Pb,Cu)_3P_2O_8$.
Bellite, Pb arseno-chromate.
Leadhillite, $PbSO_4.2PbCO_3.Pb(OH)_2$.
Caracolite, $Pb(OH)Cl.Na_2SO_4$.
Lanarkite, Pb_2SO_5.
Caledonite, $(Pb,Cu)SO_4.(Pb,Cu)(OH)_2$.
Linarite, $(Pb,Cu)SO_4.(Pb,Cu)(OH)_2$.
Beaverite, $CuO.PbO.Fe_2O_3.2SO_3.4H_2O$.
Vegasite, $PbO.3Fe_2O_3.3SO_3.6H_2O$.
Plumbojarosite, $PbFe_6(OH)_{12}(SO_4)_4$.
Palmierite, $3(K,Na)_2SO_4.4PbSO_4$.
$\left.\begin{array}{l}\text{Stolzite}\\ \text{Raspite}\end{array}\right\} PbWO_4$.
Chillagite, $3PbWO_4.PbMoO_4$.
WULFENITE, $PbMoO_4$.

LITHIUM

Petalite, $LiAl(Si_2O_5)_2$.
Spodumene, $LiAl(SiO_3)_2$.
Eucryptite, $LiAlSiO_4$.
LEPIDOLITE, Lithium mica.
Zinnwaldite, Lithium-iron mica.
Manandonite, $H_{24}Li_4Al_{14}B_4Si_6O_{53}$.
TRIPHYLITE, $Li(Fe,Mn)PO_4$.
Lithiophilite, $Li(Mn,Fe)PO$.
AMBLYGONITE, $Li(AlF)PO_4$.
Fremontite, $(Na,Li)Al(OH,F)PO_4$.
Sicklerite, $Fe_2O_3.6MnO.4P_2O_5.3(Li,H)_2O$.

MAGNESIUM

Chloromagnesite, $MgCl_2$.
Sellaite, MgF_2.
Nocerite, $2(Ca,Mg)F_2(Ca,Mg)O$.
Koenenite, Al,Mg, oxychloride.
Carnallite, $KCl.MgCl_2.6H_2O$.
Bischofite, $MgCl_2.6H_2O$.
Tachhydrite, $CaCl_2.2MgCl_2.12H_2O$.
Ralstonite, $(Na_2,Mg)F_2.3Al(F.OH)_3.2H_2O$.
Periclase, MgO.
Spinel, $MgO.Al_2O_3$.
Magnesioferrite, $MgO.Fe_2O_3$.
Jacobsite, $(Mn,Mg)O.(Fe,Mn)_2O_3$.
BRUCITE, $Mg(OH)_2$.
Hydrotalcite, $Al(OH)_3.3Mg(OH)_2.3H_2O$.
Pyroaurite, $Fe(OH)_3.3Mg(OH)_2.3H_2O$.
Dolomite, $CaCO_3.MgCO_3$.
Ankerite, $CaCO_3.(Mg,Fe,Mn)CO_3$.
Magnesite, $MgCO_3$.
Mesitite, $2MgCO_3.FeCO_3$.
Pistomesite, $MgCO_3.FeCO_3$.
Northupite, $MgCO_3.Na_2CO_3.NaCl$.
Tychite, $2MgCO_3.2Na_2CO_3.Na_2SO_4$.
Nesquehonite, $MgCO_3.3H_2O$.
Hydromagnesite, $3MgCO_3.Mg(OH)_2.3H_2O$.
Hydrogiobertite, $MgCO_3.Mg(OH)_2.2H_2O$.
Artinite, $MgCO_3.Mg(OH)_2.3H_2O$.
Lansfordite, $3MgCO_3.Mg(OH)_2.21H_2O$.
Brugnatellite, $MgCO_3.5Mg(OH)_2.Fe(OH)_3.4H_2O$.
Gajite, basic, hydrous Ca,Mg, carbonate.
Stichtite, $2MgCO_3.5Mg(OH)_2.2Cr(OH)_3$.
ENSTATITE, $MgSiO_3$.
HYPERSTHENE, $(Fe,Mg)SiO_3$.
Pyroxene, Ca,Mg, etc., silicate.
ANTHOPHYLLITE, $(Mg,Fe)SiO_3$.
Amphibole, Ca,Mg, etc., silicate.
GLAUCOPHANE, $NaAl(SiO_3)_2.(Fe,Mg)SiO_3$.
IOLITE, $H_2(Mg,Fe)_4Al_8Si_{10}O_{37}$.
Molybdophyllite, $(Pb,Mg)SiO_4.H_2O$.
Pyrope, $Mg_3Al_2(SiO_4)_3$.
Chrysolite, $(Mg,Fe)_2SiO_4$.
Monticellite, $CaMgSiO_4$.
Fosterite, Mg_2SiO_4.
Hortonolite, $(Fe,Mg,Mn)_2SiO_4$.
CHONDRODITE, $[Mg(F,OH)]_2Mg_3(SiO_4)_2$.
Humite, $[Mg(F,OH)]_2Mg_5(SiO_4)_3$.
Clinohumite, $[Mg(F,OH)]_2Mg_7(SiO_4)_4$.
Kornerupine, $MgAl_2SiO_6$.
Sapphirine, $Mg_5Al_{12}Si_2O_{27}$.
Serendibite, $10(Ca,Mg)O.5Al_2O_3.B_2O_3.6SiO_2$.
Silicomagnesiofluorite, $H_2Ca_4Mg_3Si_2O_7F_{10}$.
Lotrite, $3(Ca,Mg)O.2(Al,Fe)_2O_3.4SiO_2.2H_2O$.
Biotite, Magnesium-iron mica.
Phlogopite, Magnesium mica.
Tæniolite, K, Mg, silicate.
Seybertite, $H_3(Mg,Ca)_5Al_5Si_2O_{18}$.
Xanthophyllite, $H_8(Mg,Ca)_{14}Al_{16}Si_5O_{52}$.
Chloritoid, $H_2(Fe,Mg)Al_2SiO_7$.
Clinochlore, Penninite, $H_8Mg_5Al_2Si_3O_{18}$.
Prochlorite, Fe,Mg, chlorite.
Brunsvigite, $9(Fe,Mg)O.2Al_2O_3.6SiO_2.8H_2O$.
Griffithite, $4(Mg,Fe,Ca)O.(Al,Fe)_2O_3.5SiO_2.7H_2O$.
Spodiophyllite, $(Na_2,K_2)_2(Mg,Fe)_3(Fe,Al)_2(SiO_3)_8$.
Serpentine, $H_4Mg_3Si_2O_9$.
Deweylite, $4MgO.3SiO_2.6H_2O$.
Genthite, $2NiO.2MgO.3SiO_2.6H_2O$.
Nepouite, $3(Ni,Mg)O.2SiO_2.2H_2O$.
Garnierite, $H_2(Ni,Mg)SiO_4$ + water.
Talc, $H_2Mg_3(SiO_3)_4$.
SEPIOLITE, $H_4Mg_2Si_3O_{10}$.
Spadaite, $5MgO.6SiO_2.4H_2O$.
Saponite, Hydrous Mg,Al, silicate.
Celadonite, Fe,Mg,K, silicate.
Pholidolite, $K_2O.12(Fe,Mg)O.Al_2O_3.13SiO_2.5H_2O$.
Colerainite, $4MgO.Al_2O_3.2SiO_2.5H_2O$.
Tartarkaite, Al,Mg, hydrous silicate.
Geikielite, $(Mg,Fe)TiO_3$.
Berzeliite, $(Ca,Mg,Mn,Na_2)_3As_2O_8$.
Wagnerite, $(MgF)MgPO_4$.
Adelite, $(MgOH)CaAsO_4$.
Tilasite, $(MgF)CaAsO_4$.
Lazulite, $2AlPO_4.(Fe,Mg)(OH)_2$.
Struvite, Hydrous, NH_4,Mg, phosphate.
Pyrophosphorite, $Mg_2P_2O_7.4(Ca_3P_2O_8.Ca_2P_2O_7)$.
Roselite, $(Ca,Co,Mg)_3As_2O_8.2H_2O$.
Bobierrite, $Mg_3P_2O_8.8H_2O$.
Hœrnesite, $Mg_3As_2O_8.8H_2O$.
Cabrerite, $(Ni,Mg)_3As_2O_8.8H_2O$.
Newberyite, $HMgPO_4.3H_2O$.
$\left.\begin{array}{l}\text{Hannayite}\\ \text{Schertelite}\end{array}\right\}$ Hydrous, NH_4,Mg, phosphates.

Lüneburgite, $\mathrm{3MgO.B_2O_3.P_2O_5.8H_2O}$.
Nitromagnesite, $\mathrm{Mg(NO_3)_2.}n\mathrm{H_2O}$.
Sussexite, $\mathrm{H(Mn,Zn,Mg)BO_3}$.
Ludwigite, $\mathrm{3MgO.B_2O_3.FeO.Fe_2O_3}$.
Vonsenite, $\mathrm{3(Fe,Mg)O.B_2O_3.FeO.Fe_2O_3}$.
Magnesioludwigite, $\mathrm{3MgO.B_2O_3.MgO.Fe_2O_3}$.
Pinakiolite, $\mathrm{3MgO.B_2O_3.MnO.Mn_2O_3}$.
Szaibelyite, $\mathrm{2Mg_5B_4O_{11}.3H_2O}$.
BORACITE, $\mathrm{Mg_7Cl_2B_{16}O_{30}}$.
Ascharite, Hydrous Mg, borate.
Warwickite, $\mathrm{(Mg,Fe)_3TiB_2O_8}$.
Pinnoite, $\mathrm{MgB_2O_4.3H_2O}$.
Heintzite, Hydrous Mg,K, borate.
Hulsite, $\mathrm{12(Fe,Mg)O.2Fe_2O_3.1SnO_2.3B_2O_3.2H_2O}$.
Hydroboracite, $\mathrm{CaMgB_6O_{11}.6H_2O}$.
Sulphoborite, $\mathrm{2MgSO_4.4MgHBO_3.7H_2O}$.
Langbeinite, $\mathrm{K_2Mg_2(SO_4)_3}$.
Vanthoffite, $\mathrm{3Na_2SO_4.MgSO_4}$.
Kainite, $\mathrm{MgSO_4.KCl.3H_2O}$.
Kieserite, $\mathrm{MgSO_4.H_2O}$.
Epsomite, $\mathrm{MgSO_4.7H_2O}$.
Cupromagnesite, $\mathrm{(Cu,Mg)SO_4.7H_2O}$.
Löweite, $\mathrm{MgSO_4.Na_2SO_4.2\frac{1}{2}H_2O}$.
Blödite, $\mathrm{MgSO_4.Na_2SO_4.4H_2O}$.
Leonite, $\mathrm{MgSO_4.K_2SO_4.4H_2O}$.
Boussingaulite, $\mathrm{(NH_4)_2SO_4.MgSO_4.6H_2O}$.
Picromerite, $\mathrm{MgSO_4.K_2SO_4.6H_2O}$.
Polyhalite, $\mathrm{2CaSO_4.MgSO_4.K_2SO_4.2H_2O}$.
Hexahydrite, $\mathrm{MgSO_4.6H_2O}$.
Pickeringite, $\mathrm{MgSO_4.Al_2(SO_4)_3.22H_2O}$.
Botryogen, $\mathrm{MgO.FeO.Fe_2O_3.4SO_3.18H_2O}$.
Quetenite, $\mathrm{MgO.Fe_2O_3.3SO_3.13H_2O}$.

MANGANESE

Alabandite, MnS.
Hauerite, $\mathrm{MnS_2}$.
Samsonite, $\mathrm{2Ag_2S.MnS.Sb_2S_3}$.
Sacchite, $\mathrm{MnCl_2}$.
Chlormanganokalite, $\mathrm{4KCl.MnCl_2}$.
Manganosite, MnO.
Senaite, $\mathrm{(Fe,Mn,Pb)O.TiO_2}$.
Pyrophanite, $\mathrm{MnTiO_3}$.
Sitaparite, $\mathrm{9Mn_2O_3.4Fe_2O_3.MnO_2.3CaO}$.
Vredenburgite, $\mathrm{3Mn_3O_4.2Fe_2O_3}$.
FRANKLINITE, $\mathrm{(Fe,Zn,Mn)O.(Fe,Mn)_2O_3}$.
Jacobsite, $\mathrm{(Mn,Mg)O.(Fe,\ Mn)_2O_3}$.
Hausmannite, $\mathrm{MnO.Mn_2O_3}$.
Coronadite, $\mathrm{(Mn,Pb)Mn_3O_7}$.
Crednerite, $\mathrm{3CuO.2Mn_2O_3}$.
BRAUNITE, $\mathrm{3Mn_2O_3.MnSiO_3}$.
Bixbyite, $\mathrm{FeO.MnO_2}$.
Polianite, $\mathrm{MnO_2}$.
Pyrolusite, $\mathrm{MnO_2}$.
Manganite, $\mathrm{Mn_2O_3.H_2O}$.
Pyrochroite, $\mathrm{Mn(OH)_2}$.
Bäckströmite, $\mathrm{Mn(OH)_2}$.
Chalcophanite, $\mathrm{(Mn,Zn)O.2MnO_2.2H_2O}$
Hetærolite, $\mathrm{2ZnO.2Mn_2O_3.1H_2O}$.
Psilomelane, Hydrous Mn manganate.
Wad, Mn oxides.
Skemmatite, $\mathrm{3MnO_2.2Fe_2O_3.6H_2O}$.
Beldongrite, $\mathrm{6Mn_3O_8.Fe_2O_3.8H_2O}$.
Rhodochrosite, $\mathrm{MnCO_3}$.
Schizolite, $\mathrm{HNa(Ca,Mn)_2(SiO_3)_3}$
Låvenite, Zr-silicate of Mn, Ca.
Rhodonite, $\mathrm{MnSiO_3}$.
Pyroxmangite, Mn,Fe pyroxene.
Babingtonite, $\mathrm{(Ca,Fe,Mn)SiO_3}$ with $\mathrm{Fe_2(SiO_3)_3}$.
Margarosanite, $\mathrm{Pb(Ca,Mn)_2(SiO_3)_3}$.
Helvite, $\mathrm{(Be,Mn,Fe)_7Si_3O_{12}S}$.
Danalite, $\mathrm{(Be,Fe,Zn,Mn)_7Si_3O_{12}S}$.
Spessartite, $\mathrm{Mn_3Al_2(SiO_4)_3}$.
Partschinite, $\mathrm{(Mn,Fe)_3Al_2Si_3O_{12}}$.
Glaucochroite, $\mathrm{CaMnSiO_4}$.
Knebelite, $\mathrm{(Fe,Mn)_2SiO_4}$.
Tephroite, $\mathrm{Mn_2SiO_4}$.
Trimerite, $\mathrm{(Mn,Ca)_2SiO_4.Be_2SiO_4}$.
Friedelite, $\mathrm{H_7(MnCl)Mn_4Si_4O_{16}}$.
Pyrosmalite, $\mathrm{H_7((Fe,Mn)Cl)(Fe,Mn)_4Si_4O_{16}}$
Piedmontite, Mn epidote.
Hancockite, Pb,Mn,Ca,Al, etc., silicate.
Harstigite, Mn,Ca, silicate.
Leucophœnicite, $\mathrm{Mn_5(MnOH)_2(SiO_4)_3}$.
Ardennite, Al,Mn,V, silicate.
Långbanite, Mn silicate with Fe antimonate.
Kentrolite, $\mathrm{3PbO.2Mn_2O_3.3SiO_2}$.
Carpholite, $\mathrm{H_4MnAl_2Si_2O_{10}}$.
Pöchite, $\mathrm{H_{16}Fe_8Mn_2Si_3O_{29}}$.
Inesite, $\mathrm{H_2(Mn,Ca)_6Si_6O_{19}.3H_2O}$.
Ganophyllite, $\mathrm{7MnO.Al_2O_3.8SiO_2.6H_2O}$.
Alurgite, Manganese mica.
Dixenite, $\mathrm{MnSiO_3.2Mn_2(OH)AsO_3}$.
Bementite, $\mathrm{H_6Mn_5(SiO_4)_4}$.
Ectropite, $\mathrm{Mn_2Si_8O_{28}.7H_2O}$.
Agnolite, $\mathrm{H_2Mn_3(SiO_3)_4.H_2O}$.
Hodgkinsonite, $\mathrm{3(Zn,Mn)O.SiO_2.H_2O}$.
Gageite, Hydrous, Mn,Mg,Zn, silicate.
Caryopilite, $\mathrm{4MnO.3SiO_2.3H_2O}$.
Neotocite, Hydrous, Mn, Fe, silicate.
Astrophyllite, Na,K,Fe,Mn,Ti-silicate.
Neptunite, Fe,Mn,K,Na, titano-silicate.
COLUMBITE-TANTALITE, $\mathrm{(Fe,Mn)(Nb,Ta)_2O_6}$.
Hielmite, Y,Fe,Mn,Ca, stanno-tantalate.
Berzeliite, $\mathrm{(Ca,Mg,Mn,Na_2)_3As_2O_8}$.
Lithiophilite, $\mathrm{Li(Mn,Fe)PO_4}$.
Natrophilite, $\mathrm{NaMnPO_4}$.
Graftonite, $\mathrm{(Fe,Mn,Ca)_3P_2O_8}$.
Triplite, $\mathrm{(RF)RPO_4}$; R = Fe,Mn.
Triploidite $\mathrm{(ROH)RPO_4}$; R = Mn,Fe.
Sarkinite, $\mathrm{(MnOH)MnAsO_4}$.
Trigonite, $\mathrm{Pb_3MnH(AsO_3)_3}$.
Lacroixite, $\mathrm{Na_4(Ca,Mn)_4Al_3(F,OH)_4P_3O_{10}.2H_2O}$.
Pyrobelonite, $\mathrm{4PbO.7MnO.2V_2O_5.3H_2O}$.
Allactite, $\mathrm{Mn_3As_2O_8.4Mn(OH)_2}$.
Synadelphite, $\mathrm{2(Al,Mn)AsO_4.5Mn(OH)_2}$.
Flinkite, $\mathrm{MnAsO_4.2Mn(OH)_2}$.
Hematolite, $\mathrm{(Al,Mn)AsO_4.4Mn(OH)_2}$.
Retzian, Y,Mn,Ca, phosphate.
Arseniopleite, $\mathrm{(Mn,Ca)_9(Mn,Fe)_2(OH)_6(AsO_4)_6}$.
Manganostibiite, Mn antimonate.

Dickinsonite } Hydrous Mn,Fe,Na,
Fillowite } phosphates.
Brandite, $Ca_2MnAs_2O_8.2H_2O$.
Fairfieldite, $Ca_3MnP_2O_8.2H_2O$.
Reddingite, $Mn_3P_2O_8.3H_2O$.
Palaite, $5MnO.2P_2O_5.4H_2O$.
Stewartite, $3MnO.P_2O_5.4H_2O$.
Purpurite, $2(Fe,Mn)PO_4.H_2O$.
Sicklerite, $Fe_2O_3.6MnO.4P_2O_5.3(Li,H)_2O$.
Salmonsite, $Fe_2O_3.9MnO.4P_2O_5.14H_2O$.
Hureaulite, $H_2Mn_5(PO_4)_4.4H_2O$.
Hemafibrite, $Mn_3As_2O_8.3Mn(OH)_2.2H_2O$.
Eosphorite, $2AlPO_4.2(Mn,Fe)(OH)_2.2H_2O$.
Roschérite, $(Mn,Fe,Ca)_2Al(OH)(PO_4)_2.2H_2O$
Catoptrite, $14(Mn,Fe)O.2(Al,Fe)_2O_3.2SiO_2.Sb_2O_5$.
Sussexite, $H(Mn,Zn,Mg)BO_3$.
Pinakiolite, $3MgO.B_2O_3.MnO.Mn_2O_3$.
Szmikite, $MnSO_4.H_2O$.
Ilesite, $(Mn,Zn,Fe)SO_4.4H_2O$.
Mallardite, $MnSO_4.7H_2O$.
Apjohnite, $MnSO_4.Al_2(SO_4)_3.24H_2O$.
Dietrichite, $(Zn,Fe,Mn)SO_4.Al_2(SO_4)_3.22H_2O$.
Hübnerite, $MnWO_4$.

MERCURY

Native Mercury, Hg.
Amalgam, (Ag,Hg).
Metacinnabarite, HgS.
Tiemannite, HgSe.
Onofrite, Hg(S,Se).
Coloradoite, HgTe.
Cinnabar, HgS.
Livingstonite, $HgS.2Sb_2S_3$.
Calomel, HgCl.
Kleinite, Hg,NH_4, chloride.
Eglestonite, Hg_4Cl_2O.
Terlinguaite, HgClO.
Mosesite, Hydrous Hg,NH_4, chloride.
Montroydite, HgO.
Ammiolite, Hg antimonite.

MOLYBDENUM

Molybdenite, MoS_2.
Molybdite, MoO_3.
Powellite, $Ca(Mo,W)O_4$.
Chillagite, $3PbWO_4.PbMoO_4$.
WULFENITE, $PbMoO_4$.
Koechlinite, $Bi_2O_3.MoO_3$.

NICKEL

Awaruite, $FeNi_2$.
Josephinite, $FeNi_3$.
Maucherite, Ni_3As_2.
PENTLANDITE, (Fe,Ni)S.
Millerite, NiS.
Beyrichite, NiS.
Hauchecornite, Ni(Bi,Sb,S)?
Niccolite, NiAs.
Breithauptite, NiSb.
Polydymite, Ni_4S_5.
Badenite, $(Co,Ni,Fe)_2(As,Bi)_3$.
Bravoite, $(Fe,Ni)S_2$.
Cobaltnickelpyrite, $(Co,Ni,Fe)S_2$.
CHLOANTHITE, $NiAs_2$.
Gersdorffite, NiAsS.
Willyamite, $CoS_2.NiS_2.CoSb_2.NiSb_2$.
Villamaninite, Cu,Ni,Co,Fe, sulphide.
Ullmanite, NiSbS.
Kallilite, Ni(Sb,Bi)S.
Rammelsbergite, $NiAs_2$.
Wolfachite, Ni(As,Sb)S.
Melonite, $NiTe_2$.
Bunsenite, NiO.
Zaratite, $NiCO_3.2Ni(OH)_2.4H_2O$.
Genthite, $2NiO.2MgO.3SiO_2.6H_2O$.
Nepouite, $3(Ni,Mg)O.2SiO_2.2H_2O$.
Garnierite, $H_2(Ni,Mg)SiO_4$ + water.
Connarite, $H_4Ni_2Si_3O_{10}$.
Annabergite, $Ni_3As_2O_8.8H_2O$.
Cabrerite, $(Ni,Mg)_3As_2O_8.8H_2O$.
Forbesite, $H_2(Ni,Co)_2As_2O_8.8H_2O$.
Lindackerite, $3NiO.6CuO.SO_3.2As_2O_5.7H_2O$.
Morenosite, $NiSO_4.7H_2O$.

PLATINUM

Native Platinum, Pt.
Sperrylite, $PtAs_2$.

POTASSIUM

SYLVITE, KCl.
Chlormanganokalite, $4KCl.MnCl_2$.
Rinneite, $FeCl_2.3KCl.NaCl$.
Hieratite, K,Si, fluoride.
CARNALLITE, $KCl.MgCl_2.6H_2O$.
Kremersite, $KCl,NH_4Cl.FeCl_2.H_2O$.
Erythrosiderite, $2KCl.FeCl_3.H_2O$.
Milarite, $HKCa_2Al_2(Si_2O_5)_6$.
Orthoclase, **Microcline**, $KAlSi_3O_8$.
Hyalophane, $(K_2,Ba)Al_2(SiO_3)_4$.
Anorthoclase, $(Na,K)AlSi_3O_8$.
Leucite, $KAl(SiO_3)_2$.
Kaliophilite, $KAlSiO_4$.
Apophyllite, $H_7KCa_4(SiO_3)_8.4\frac{1}{2}H_2O$.
Ptilolite, $(Ca,K_2,Na_2)Al_2Si_{10}O_{24}.5H_2O$.
Mordenite, $(Ca,K_2,Na_2)Al_2Si_{10}O_{24}.20H_2O$.
Wellsite, $(Ba,Ca,K_2)Al_2Si_3O_{10}.3H_2O$.
Phillipsite, $(K_2,Ca)Al_2Si_4O_{12}.4\frac{1}{2}H_2O$.
Harmotone, $(K_2,Ba)Al_2Si_5O_{14}.5H_2O$.
Offretite, Potash zeolite.
Muscovite, $H_2KAl_3(SiO_4)_3$.
Tæniolite, K,Mg, silicate.
Spodiophyllite, $(Na_2K_2)_2(Mg,Fe)_3(Fe,Al)_2(SiO_3)_8$.
Celadonite, Fe,Mg,K, silicate.
Glauconite, Hydrous Fe, K, silicate.
Astrophyllite, Na,K,Mn,Fe, titano-silicate.
Palmerite, $HK_2Al_2(PO_4)_3.7H_2O$.
Carnotite, $K_2O.2U_2O_3.V_2O_5.3H_2O$.
Niter, KNO_3.
Rhodizite, Al,K, borate.
Heintzite, Hydrous Mg,K, borate.
Taylorite, $5K_2SO_4.(NH_4)_2SO_4$.
Aphthitalite, $(K,Na)_2SO_4$.
Langbeinite, $K_2Mg_2(SO_4)_3$.

Kainite, $MgSO_4.KCl.3H_2O$.
Hanksite, $9Na_2SO_4.2Na_2CO_3.KCl$.
Misenite, $HKSO_4$.
Lecontite, $(Na,NH_4,K)SO_4.2H_2O$.
Syngenite, $CaSO_4.K_2SO_4.H_2O$.
Leonite, $MgSO_4.K_2SO_4.4H_2O$.
Picromerite, $MgSO_4.K_2SO_4.6H_2O$.
Polyhalite, $2CaSO_4.MgSO_4.K_2SO_4.2H_2O$.
Kalinite, $KAl(SO_4)_2.12H_2O$.
Voltaite, $3(K_2,Fe)O.2(Al,Fe)_2O_3.6SO_3.9H_2O$.
Metavoltine, $5(K_2,Na_2,Fe)O.3Fe_2O_3.12SO_3.18H_2O$.
ALUNITE, $K_2Al_6(OH)_{12}(SO_4)_4$.
Jarosite, $K_2Fe_6(OH)_{12}(SO_4)_4$.
Palmierite, $3(K,Na)_2SO_4.4PbSO_4$.
Löwigite, $K_2O.3Al_2O_3.4SO_3.9H_2O$.

SILVER

Native Silver, Ag.
Amalgam, (Ag,Hg).
Dyscrasite, Ag_3Sb.
Chilenite, Ag_6Bi.
Cocinerite, Cu_4AgS.
Stützite, Ag_4Te.
Naumannite, $(Ag_2,Pb)Se$
Argentite, Ag_2S.
Hessite, Ag_2Te.
Petzite, $(Ag,Au)_2Te$.
Aquilarite, $Ag_2(S,Se)$.
Eucairite, $Cu_2Se.Ag_2Se$.
Crookesite, $(Cu,Tl,Ag)_2Se$.
Stromeyrite, $(Ag,Cu)_2S$.
Acanthite, Ag_2S.
Sternbergite, $Ag_2S.Fe_4S_5$.
Sylvanite, $(Au,Ag)Te_2$.
Krennerite, $(Au,Ag)Te_2$.
Muthmannite, $(Ag,Au)Te$.
Andorite, $Ag_2S.2PbS.3Sb_2S_3$.
Matildite, $Ag_2S.Bi_2S_3$.
Miargyrite, $Ag_2S.Sb_2S_3$.
Smithite, $Ag_2S.Sb_2S_3$.
Trechmanite, $Ag_2S.As_2S_3$.
Hutchinsonite, $(Tl,Ag,Cu)_2S.As_2S_3 + PbS.As_2S_3$(?).
Schirmerite, $3(Ag_2.Pb)S.2Bi_2S_3$.
Freieslebenite, $5(Pb,Ag_2)S.2Sb_2S_3$.
Diaphorite, $5(Pb,Ag_2)S.2Sb_2S_3$.
Stylotypite, $3(Cu_2,Ag_2,Fe)S.Sb_2S_3$.
Lengenbachite, $7[Pb,(Ag,Cu)_2]S.2As_2S_3$.
PYRARGYRITE, $3Ag_2S.Sb_2S_3$.
PROUSTITE, $3Ag_2S.As_2S_3$.
Pyrostilpnite, $3Ag_2S.Sb_2S_3$.
Samsonite, $2Ag_2S.MnS.Sb_2S_3$.
STEPHANITE, $5Ag_2S.Sb_2S_3$.
POLYBASITE, $9Ag_2S.Sb_2S_3$.
Pearceite, $9Ag_2S.As_2S_3$.
Polyargyrite, $12Ag_2S.Sb_2S_3$.
Xanthoconite, $3Ag_2S.As_2S_5$.
Argyrodite, $4Ag_2S.GeS_2$.
Canfieldite, $4Ag_2S.SnS_2$.
Cerargyrite, AgCl.
Embolite, Ag(Br,Cl).
Bromyrite, AgBr.
Iodobromite, 2AgCl.2AgBr.AgI.
Miersite, 4AgI.CuI.
Iodyrite, AgI.

SODIUM

Halite, NaCl.
Villiaumite, NaF.
Huantajayite, 20NaCl.AgCl.
Rinneite, $FeCl_3.3KCl.NaCl$.
CRYOLITE, Na_3AlF_6.
Chiolite, $5NaF.3AlF_3$.
Ralstonite, $(Na_2,Mg)F_2.3Al(F,OH)_3.2H_2O$.
Northupite, $MgCO_3.Na_2CO_3.NaCl$.
Tychite, $2MgCO_3.2Na_2CO_3.Na_2SO_4$.
Dawsonite, $Na_3Al(CO_3)_3.2Al(OH)_3$.
Thermonatrite, $Na_2CO_3.H_2O$.
Natron, $Na_2CO_3.10H_2O$.
Pirssonite, $CaCO_3.Na_2CO_3.2H_2O$.
Gay-Lussite, $CaCO_3.Na_2CO_3.5H_2O$.
Trona, $Na_2CO_3.HNaCO_3.2H_2O$.
Eudidymite, Epididymite, $HNaBeSi_3O_8$.
Rivaite, $(Ca,Na_2)Si_2O_5$.
Anorthoclase, $(Na,K)AlSi_3O_8$.
Albite, $NaAlSi_3O_8$.
Oligoclase
Andesine } Mixtures of $NaAlSi_3O_8$ and $CaAl_2Si_2O_8$.
Labradorite
Anemousite, $NaO.2CaO.3Al_2O_3.9SiO_2$.
Ussingite, $HNa_2Al(SiO_3)_3$.
ACMITE, $NaFe(SiO_3)_2$.
JADEITE, $NaAl(SiO_3)_2$.
PECTOLITE, $HNaCa_2(SiO_3)_3$.
Schizolite, $HNa(Ca,Mn)_2(SiO_3)_3$.
Rosenbuschite, near pectolite with Zr.
Wöhlerite, Zr-silicate and niobate of Ca,Na.
Hiortdahlite, $(Na_2.Ca)(Si,Zr)O_3$.
GLAUCOPHANE, $NaAl(SiO_3)_2.(Fe,Mg)SiO_3$.
RIEBECKITE, $2NaFe(SiO_3)_2.FeSiO_3$.
CROCIDOLITE, $NaFe(SiO_3)_2.FeSiO_3$.
Arfvedsonite, Na,Ca,Fe″ silicate.
Ænigmatite, Fe,Na,Ti-silicate.
Weinbergerite, $NaAlSiO_4.3FeSiO_3$.
Elpidite, $Na_2O.ZrO_2.6SiO_2.3H_2O$.
Catapleiite, $H_4(Na_2,Ca)ZrSi_3O_{11}$.
Leucophanite } Na,Be,Ca, fluo-silicates.
Meliphanite
Nephelite, $NaAlSiO_4$.
CANCRINITE, $H_6Na_6Ca(NaCO_3)_2Al_8(SiO_4)_9$.
Microsommite, Davyne, near cancrinite.
SODALITE, $Na_4(AlCl)Al_2(SiO_4)_3$
Hackmanite, near sodalite.
HAÜYNITE, $(Na_2,Ca)_2(NaSO_4.Al)Al_2(SiO_4)_3$.
Noselite, $Na_4(NaSO_4.Al)Al_2(SiO_4)_3$.
LAZURITE, $Na_4(NaS_3.Al)Al_2(SiO_4)_3$.
SCAPOLITE GROUP, Mixtures of $Ca_4Al_6Si_6O_{25}$ and $Na_4Al_3Si_9O_{24}Cl$.
Sarcolite, $(Ca,Na_2)_3Al_2(SiO_4)_3$.
Melilite, $Na_2(Ca,Mg)_{11}(Al,Fe)_4(SiO_4)_9$.
Mordenite, $(Ca,K_2,Na_2)Al_2Si_{10}O_{24}.20H_2O$.
Stilbite, $(Na_2,Ca)Al_2Si_6O_{16}.6H_2O$.

Flokite, $H_8(Ca,Na_2)Al_2Si_9O_{26}.2H_2O$.
CHABAZITE, $(Ca,Na_2)Al_2Si_4O_{12}.6H_2O$.
Gmelinite, $(Na_2Ca)Al_2Si_4O_{12}.6H_2O$.
Analcite, $NaAlSi_2O_6.H_2O$.
Faujasite, $H_4Na_2CaAl_4Si_{10}O_{30}.18H_2O$.
Natrolite, $Na_2Al_2Si_3O_{10}.2H_2O$.
Mesolite, $Na_2Al_2Si_3O_{10}.2H_2O + 2[CaAl_2Si_3O_{10}.3H_2O]$.
Gonnardite, $(Ca,Na_2)_2Al_2Si_5O_{15}.5\frac{1}{2}H_2O$.
Thomsonite, $(Na_2,Ca)Al_2Si_2O_8.2\frac{1}{2}H_2O$.
Hydrothomsonite, $(H_2,Na_2,Ca)Al_2Si_2O_8.5H_2O$.
Arduinite, Ca,Na, zeolite.
Echellite, $(Ca,Na_2)O.2Al_2O_3.3SiO_2.4H_2O$.
Epidesmine, $(Na_2,Ca)Al_2Si_6O_{16}.6H_2O$.
Erionite, $H_2CaK_2Na_2Al_2Si_6O_{17}.5H_2O$.
Hydronephelite, $HNa_2Al_3Si_3O_{12}.3H_2O$.
Paragonite, $H_2NaAl_3(SiO_4)_3$.
Spodiophyllite, $(Na_2,K_2)_2(Mg,Fe)_3(Fe,Al)_2(SiO_3)_8$.
Searlesite, $NaB(SiO_3)_2.H_2O$.
Molengraafite, Ca,Na, titano-silicate.
Astrophyllite, Na,K,Mn,Fe,titano-silicate.
Narsarsukite, Fe,Na,titano-silicate.
Leucosphenite, $Na_4Ba(TiO)_2(Si_2O_5)_5$.
Lorenzenite, $Na_2(TiO)_2Si_2O_7$.
Epistolite, Ti,Na,etc., niobate.
Berzeliite, $(Ca,Mg,Mn,Na_2)_3As_2O_8$.
Natrophilite, $NaMnPO_4$.
Beryllonite, $NaBePO_4$.
Ježekite, $Na_4CaAl(AlO)(F,OH)_4(PO_4)_2$.
Lacroixite, $Na_4(Ca,Mn)_4Al_3(F,OH)_4P_4O_{16}.2H_2O$.
Durangite, $Na(AlF)AsO_4$.
Fremontite, $(Na,Li)Al(OH,F)PO_4$.
Dickinsonite
Fillowite } $3(Mn,Fe,Na_2)_3P_2O_8.H_2O$.
Stercorite, $HNa(NH_4)PO_4.4H_2O$.
Soumansite, Hydrous Al,Na, fluophosphate.
SODA NITER, $NaNO_3$.
Darapskite, $NaNO_3.Na_2SO_4.H_2O$.
Nitroglauberite, $6NaNO_3.2Na_2SO_4.3H_2O$.
Borax, $Na_2B_4O_7.10H_2O$.
Ulexite, $NaCaB_5O_9.8H_2O$.
Thenardite, Na_2SO_4.
Aphthitalite, $(K,Na)_2SO_4$.
GLAUBERITE, $Na_2SO_4.CaSO_4$.
Vanthoffite, $3Na_2SO_4.MgSO_4$.
Sulphohalite, $3Na_2SO_4.NaCl.NaF$.
Caracolite, $Pb(OH)Cl.Na_2SO_4$.
Hanksite, $9Na_2SO_4.2Na_2CO_3.KCl$.
Lecontite, $(Na,NH_4,K)_2SO_4.2H_2O$.
Mirabilite, $Na_2SO_4.10H_2O$.
Löweite, $MgSO_4.Na_2SO_4.2\frac{1}{2}H_2O$.
Blödite, $MgSO_4.Na_2SO_4.4H_2O$.
Mendozite, $NaAl(SO_4)_2.12H_2O$.
Kröhnkite, $CuSO_4.Na_2SO_4.2H_2O$.
Natrochalcite, $Cu_4(OH)_2(SO_4)_2.Na_2SO_4.2H_2O$.
Ferronatrite, $3Na_2SO_4.Fe_2(SO_4)_3.6H_2O$.
Sideronatrite, $2Na_2O.Fe_2O_3.4SO_3.7H_2O$.
Metavoltine, $5(K_2,Na_2,Fe)O.3Fe_2O_3.12SO_3.18H_2O$.
Natrojarosite, $Na_2Fe_6(OH)_{12}(SO_4)_4$.
Palmierite, $3(K,Na)_2SO_4.4PbSO_4$.
Almeriite, $Na_2SO_4.Al_2(SO_4)_3.5Al(OH)_3.H_2O$.

STRONTIUM

Strontianite, $SrCO_3$.
Ancylite, $4Ce(OH)CO_3.3SrCO_3.3H_2O$.
Ambatoarinite, Rare earths, Sr, carbonate.
Brewsterite, $H_4(Sr,Ba,Ca)Al_2(SiO_3)_6.3H_2O$.
Fermorite, $(Ca,Sr)_4[Ca(OH,F)][(P,As)O_4]_3$.
Hamlinite, Sr,Al, phosphate.
Harttite, Sr,Al, phosphate and sulphate.
Celestite, $SrSO_4$.

THORIUM

Caryocerite
Tritomite } Ca,Ce,Y,Th, fluo-silicates.
Thorite, $ThSiO_4$.
Auerlite, Th silico-phosphate.
Yttrialite, Th,Y, silicate.
Mackintoshite, U,Th,Ce, silicate.
Yttrocrasite, Hydrous Y,Th, titanate.
Pyrochlore, $RNb_2O_6.R(Ti,Th)O_3$.
MONAZITE, $(Ce,La,Di)PO_4$ with ThO_2.
Thorianite, Th and U oxides.

TIN

Stannite, $Cu_2S.FeS.SnS_2$.
Canfieldite, $4Ag_2S.SnS_2$.
Teallite, $PbSnS_2$.
Franckeite, $Pb_5Sn_3FeSb_2S_{14}$.
Cylindrite, $Pb_3Sn_4FeSb_2S_{14}$.
Cassiterite, SnO_2.
Stokesite, $H_4CaSnSi_3O_{11}$.
Hielmite, Y,Fe,Mn,Ca, stanno-niobate.
Nordenskiöldine, $CaSn(BO_3)_2$.
Hulsite, $12(Fe,Mg)O.2Fe_2O_3.1SnO_2.3B_2O_3.2H_2O$.

TITANIUM

ILMENITE, $FeTiO_3$.
Senaite, $(Fe,Mn,Pb)O.TiO_2$.
Arizonite, $Fe_2O_3.3TiO_2$.
Pyrophanite, $MnTiO_3$.
Pseudobrookite, $Fe_4(TiO_4)_3$.
Rutite, TiO_2.
Octahedrite, Brookite, TiO_2.
Uhligite, $Ca(Ti,Zr)O_5.Al(Ti,Al)O_5$.
Schlorlomite, $Ca_3(Fe,Ti)_2((Si,Ti)O_4)_3$.
Titanite, $CaTiSiO_5$.
Molengraafite, Ca,Na, titano-silicate.
Keilhauite, Ca,Al,Fe,Y, titano-silicate.
Tscheffkinite, Ce, etc., titano-silicate.
Astrophyllite, Na,K,Fe,Mn, titano-silicate.
Johnstrupite
Mosandrite } Ce, etc., titano-silicates
Rinkite
Narsarsukite, Fe,Na, titano-silicate.
Neptunite, Fe,Mn,Na,K, titano-silicate.
Benitoite, $BaTiSi_3O_9$.
Leucosphenite, $Na_4Ba(TiO)_2(Si_2O_5)_5$.
Lorenzenite, $Na_2(TiO)_2Si_2O_7$.
Joaquinite, Ca,Fe, titano-silicate.
PEROVSKITE, $CaTiO_3$.
Knopite, Ca,Ce, titanate.

Dysanalyte, Ca,Fe, titano-silicate.
Geikielite, Mg,Fe, titanate.
Delorenzite, Fe,U,Y, titanate.
Yttrocrasite, Hydrous Y, Th, titanate.
Brannerite, $(UO,TiO,UO_2)TiO_3$.
Pyrochlore, $RNb_2O_6.R(Ti,Th)O_3$.
Aeschynite, Ce, niobate-titanate.
Polymignite, Ce,Fe,Ca, niobate-titanate.
$\left.\begin{array}{l}\text{Euxenite}\\ \text{Polycrase}\\ \text{Blomstrandine-Priorite}\end{array}\right\}$ Y,Ce,U, niobate-titanates.
Betafite, U, etc., niobate-titanate.
Epistolite, Na,Ti, etc., niobate.
Lewisite, $5CaO.2TiO_2.3Sb_2O_5$.
Mauzeliite, Pb,Ca, titano-antimonate.
Warwickite, $(Mg,Fe)_3TiB_2O_8$.

TUNGSTEN

Tungstenite, WS_2.
Tungstite, WO_3.
WOLFRAMITE, $(Fe,Mn)WO_4$.
Hübnerite, $MnWO_4$.
SCHEELITE, $CaWO_4$.
Cuprotungstite, $CuWO_4$.
Powellite, $Ca(Mo,W)O_4$.
$\left.\begin{array}{l}\text{Stolzite}\\ \text{Raspite}\end{array}\right\}$ $PbWO_4$.
Chillagite, $3PbWO_4.PbMoO_4$.
Reinite, $FeWO_4$.
Ferritungstite, $Fe_2O_3.WO_3.6H_2O$.

URANIUM

Rutherfordine, UO_2CO_3.
Uranothallite, $2CaCO_3.U(CO_3)_2.10H_2O$.
Liebigite, Hydrous, U,Ca, carbonate.
Voglite, Hydrous, U, Ca, Cu, carbonate.
Mackintoshite, U,Th,Ce, silicate.
Uranophane, $CaO.2UO_3.2SiO_2.6H_2O$.
Delorenzite, Fe,U,Y, titanate.
Brannerite, $(UO,TiO,UO_2)TiO_3$.
Hatchettolite, U, tantalo-niobate.
Samirésite, U, etc., niobate.
Fergusonite, Y,Er,U, niobate.
Samarskite, Fe,Ca,U,Ce,Y, niobate.
Ampangabéite, U, etc., niobate.
Ånnerödite, U,Y, niobate.
$\left.\begin{array}{l}\text{Euxenite}\\ \text{Polycrase}\\ \text{Blomstrandine-Priorite}\end{array}\right\}$ Y,Ce,U, niobate-titanates.
Betafite, U, niobate-titanate.
Plumboniobite, Y,U,Pb, niobate.
Uvanite, $2UO_3.3V_2O_5.15H_2O$.
Ferganite, $U_3(VO_4)_2.6H_2O$.
Torbernite, $Cu(UO_2)_2P_2O_8.8H_2O$.
Zeunerite, $Cu(UO_2)_2As_2O_8.8H_2O$.
$\left.\begin{array}{l}\text{Autunite}\\ \text{Bassetite}\end{array}\right\}$ $Ca(UO_2)_2P_2O_8.8H_2O$.
Uranospinite, $Ca(UO_2)_2As_2O_8.8H_2O$.
Uranocircite, $Ba(UO_2)_2P_2O_8.8H_2O$.
CARNOTITE, $K_2O.2U_2O.V_2O_5.3H_2O$.
Tyuyamunite, $CaO.2UO_3.V_2O_5.4H_2O$.
Uranospathite, Hydrous uranyl phosphate.
Phosphuranylite, $(UO_2)_3P_2O_8.6H_2O$.
Trögerite, $(UO_2)_3As_2O_8.12H_2O$.
Walpurgite, $Bi_{10}(UO_2)_3(OH)_{24}(AsO_4)_4$.
URANINITE, Uranyl, etc., uranate.
Gummite, alteration of uraninite.
Thorianite, Th and U oxides.
Uranosphærite, $(BiO)_2U_2O_7.3H_2O$.
Johannite, Hydrous Cu,U, sulphate.
Gilpinite, $(Cu,Fe,Na_2)O.UO_3.SO_3.4H_2O$.
Uranopilite, $CaU_8S_2O_{31}.25H_2O$.

VANADIUM

PATRONITE, VS_4.
Sulvanite, $3Cu_2S.V_2S_5$.
Alaïte, $V_2O_5.H_2O$.
Ardennite, Al,Mn,V, silicate.
Roscoelite, Vanadium mica.
Pucherite, $BiVO_4$.
Vanadinite, $Pb_4(PbCl)(VO_4)_3$.
Descloizite, $(Pb,Zn)_2(OH)VO_4$.
Pyrobelonite, $4PbO.7MnO.2V_2O_5.3H_2O$.
Dechenite, PbV_2O_6.
Calciovolborthite, $(Cu,Ca)_3V_2O_8.(Cu,Ca)(OH)_2$.
Turanite, $5CuO.V_2O_5.2H_2O$.
$\left.\begin{array}{l}\text{Psittacinite}\\ \text{Mottramite}\end{array}\right\}$ Pb,Cu, vanadates.
Uvanite, $2UO_3.3V_2O_5.15H_2O$.
Ferganite, $U_3(VO_4)_2.6H_2O$.
Fernandinite, $CaO.V_2O_4.5V_2O_5.14H_2O$.
Pascoite, $2CaO.3V_2O_5.11H_2O$.
Pintadoite, $2CaO.V_2O_5.9H_2O$.
$\left.\begin{array}{l}\text{Hewettite}\\ \text{Metahewettite}\end{array}\right\}$ $CaO.3V_2O_5.9H_2O$.
Volborthite, Hydrous, Cu,Ba,Ca, vanadate.
Hügelite, Hydrous, Pb,Zn, vanadate.
CARNOTITE, $K_2O.2U_2O_3.V_2O_5.3H_2O$.
Tyuyamunite, $CaO.2UO_3.V_2O_5.4H_2O$.
Minasragrite, $(V_2O_2)H_2(SO_4)_3.15H_2O$.

YTTRIUM, Etc.

Yttrofluorite, $(Ca_3,Y_2)F_6$.
Yttrocerite, $(Y,Er,Ce)F_3.5CaF_2.H_2O$.
Tengerite, Y carbonate.
Cappelenite, Y,Ba, boro-silicate.
$\left.\begin{array}{l}\text{Melanocerite}\\ \text{Caryocerite}\\ \text{Steenstrupine}\end{array}\right\}$ Ca,Y,Ce, fluo-silicates.
Tritomite, Th,Ce,Y,Ca, fluo-silicate.
Gadolinite, $Be_2FeY_2Si_2O_{10}$.
Yttrialite, Th,Y, silicate.
Rowlandite, Y silicate.
Thalénite, Y silicate
Thortveitite, $(Sc,Y)_2Si_2O_7$.
Cenosite, $H_4Ca_2(Y,Er)_2CSiO_{17}$.
Keilhauite, Ca,Al,Fe,Y, titano-silicate.
Delorenzite, Fe,U,Y, titanate.
Yttrocrasite, Hydrous Y,Th, titanate.
Risörite, Y niobate.
Fergusonite, Y,Er, niobate.
Sipylite, Er niobate.
Yttrotantalite, Y, etc., tantalate-niobate.

Samarskite, Fe,Ca,U,Ce,Y, niobate-tantalate.
Ånnerödite, U,Y, niobate.
Hielmite, Y,Fe,Mn,Ca, stanno-tantalate.
$\left.\begin{array}{l}\text{Euxenite}\\ \text{Polycrase}\\ \text{Blomstrandine-Priorite}\end{array}\right\}$ Y,Ce,U, niobate-titanates.
Plumboniobite, Y,U,Pb,Fe, niobate.
XENOTIME, YPO_4.
Retzian, Y,Mn,Ca, arsenate.
Rhabdophanite, Hydrous Ce,Y, phosphate.

ZINC

Sphalerite, ZnS.
Wurtzite, ZnS.
Voltzite, Zn_5S_4O.
ZINCITE, ZnO.
Gahnite, $ZnO.Al_2O_3$.
FRANKLINITE, $(Fe,Zn,Mn)O.(Fe,Mn)_2O_3$.
Chalcophanite, $(Mn,Zn)O.2MnO_2.2H_2O$.
Hetærolite, $2ZnO.2Mn_2O_3.1H_2O$.
Smithsonite, $ZnCO_3$.
Rosasite, $2CuO.CuCO_3.5ZnCO_3$?
Aurichalcite, $2(Zn,Cu)CO_3,3(Zn,Cu)(OH)_2$.
Hydrozincite, $ZnCO_3.2Zn(OH)_2$.
Hardystonite, $Ca_2ZnSi_2O_7$.
Danalite, $(Be,Fe,Zn,Mn)_7Si_3O_{12}S$.
Willemite, Zn_2SiO_4.
Calamine, H_2ZnSiO_5.
Clinohedrite, $H_2CaZnSiO_5$.
Hodgkinsonite, $3(Zn,Mn)O.SiO_2.H_2O$.
Gageite, Hydrous, Mn, Mg, Zn, silicate.
Tarbuttite, $Zn_3P_2O_8.Zn(OH)_2$.
Adamite, $Zn_2(OH)AsO_4$.
Descloizite, $(Pb,Zn)_2(OH)VO_4$.
$\left.\begin{array}{l}\text{Hopeite}\\ \text{Parahopeite}\end{array}\right\}Zn_3P_2O_8.4H_2O$.
Köttigite, $Zn_3As_2O_8.8H_2O$.
Barthite, $3ZnO.CuO.3As_2O_5.2H_2O$.
Hügelite, Hydrous, Pb, Zn, vanadate
Spencerite, $Zn_3(PO_4)_2.Zn(OH)_2.3H_2O$.
Hibbenite, $2Zn_3(PO_4)_2.Zn(OH)_2.6\frac{1}{2}H_2O$.
Veszelyite, Hydrous, Cu, Zn, phospho-arsenate.
Kehoeite, Hydrous, Al, Zn, phosphate.
Sussexite, $H(Mn,Zn,Mg)BO_3$.
Zinkosite, $ZnSO_4$.
Ilesite, $(Mn,Zn,Fe)SO_4.4H_2O$.
Goslarite, $ZnSO_4.7H_2O$.
Dietrichite, $(Zn,Fe,Mn)SO_4.Al_2(SO_4)_3.22H_2O$.
Serpierite, Hydrous, Cu, Zn, sulphate.
Zincaluminite, $2ZnSO_4.4Zn(OH)_2.6Al(OH)_3.5H_2O$.

ZIRCONIUM

Baddeleyite, ZrO_2.
Uhligite, $Ca(Ti,Zr)O_5.Al(Ti,Al)O_5$.
Rosenbuschite, Na,Ca,Zr, silicate.
Wöhlerite, Na,Ca,Zr, silicate and niobate.
Låvenite, Mn,Ca,Zr, silicate.
Hiortdahlite, $(Na_2,Ca)(Si,Zr)O_3$.
Eudialyte, Zr,Fe,Ca,Na, silicate.
Elpidite, $Na_2O.ZrO_2.6SiO_2.3H_2O$.
Catapleiite, $H_4(Na_2,Ca)ZrSi_3O_{11}$.
Zircon, $Zr\ SiO_4$.
Chalcolamprite, $R''Nb_2O_6.R''SiO_3$.

TABLE II. MINERALS ARRANGED ACCORDING TO THEIR SYSTEM OF CRYSTALLIZATION.

The following lists are intended to include all well-recognized species, whose crystallization is known, arranged according to the system to which they belong, and further classified by their luster and specific gravity; the hardness is also given in each case.

I. CRYSTALLIZATION ISOMETRIC.*

A. Luster Nonmetallic.

	Specific Gravity.	Hardness.		Specific Gravity.	Hardness.
Sal Ammoniac (p. 397).	1·53	1·5–2	Arsenolite (p. 409).....	3·7	1·5
Kalinite (p. 637)......	1·75	2–2·5	Schorlomite (p. 510)...	3·81–3·88	7–7·5
Faujasite (p. 555).....	1·92	5	Betafite (p. 591)......	3·75–4·17	
Sylvite (p. 396)........	1·98	2	Hercynite (p. 420).....	3·9–3·95	7·5–8
Halite (p. 395).......	2·14	2·5	**Sphalerite** (p. 367).....	3·9–4·1	3·5–4
Hydrophilite (p. 399)..	2·2		Nantokite (p. 395).....	3·93	2–2·5
Sodalite (p. 502).......	2·14–2·30	5·5–6	Marshite (p. 395)......	5·6?	
Analcite (p. 554).......	2·2–2·3	5–5·5	Alabandite (p. 369)....	3·95–4·04	3·5–4
Noselite (p. 503)......	2·25–2·4	5·5	Perovskite (p. 586)....	4·03	5·5
Northupite (p. 450)....	2·38	3·5–4	Berzeliite (p. 593).....	4·08	5
Haüynite (p. 503).....	2·4–2·5	5·5–6	**Gahnite** (p. 420).......	4·0–4·6	7·5–8
Leucite (p. 469).......	2·45–2·50	5·5–6	Pyrochlore (p. 587)....	4·2–4·36	5–5·5
Lazurite (p. 503).......	2·38–2·45	5–5·5	Koppite (p. 587)......	4·45–4·56	
Sulphohalite (p. 631)...	2·49	3·5	Zirkelite (p. 428)......	4·71	5·5
Tychite (p. 450).......	2·5	3·5	Hatchettolite (p. 587)..	4·8–4·9	5
Ralstonite (p. 402)....	2·58	4·5	Lewisite (p. 618)......	4·95	5·5
Voltaite (p. 639).......	2·79	3–4	Atopite (p. 618).......	5·03	5·5–6
Villiaumite (p. 396)....	2·81		Percylite, Boleite		
Langbeinite (p. 625)...	2·83		(p. 401)............	5·08	2·5
Zunyite (p. 505).......	2·87	7	Mauzeliite (p. 618)....	5·11	6–6·5
Pollucite (p. 470)......	2·90	6·5	Manganosite (p. 411)..	5·18	5–6
Boracite (p. 620)......	2·9–3	7	Neotantalite (p. 587)...	5·2	3·8
Pharmacosiderite,			Senarmontite (p. 409)..	5·2–5·3	2–2·5
(p. 614)............	2·9–3	2·5	Samirésite (p. 587)....	5·24	
Plazolite (p. 580).....	3·13	6·5	Embolite (p. 397).....	5·3–5·4	1–1·5
Nitrobarite (p. 619)....	3·2		**Cerargyrite** (p. 397)....	5·55	1–1·5
Fluorite (p. 398).......	3·2	4	Miersite (p. 598)......	5·6	
Helvite (p. 504).......	3·16–3·36	6–6·5	Microlite (p. 587).....	5·5–6·1	5·5
Garnet (p. 505).......	3·3–4·3	6·5–7·5	Iodobromite (p. 397)...	5·71	1–1·5
Rhodizite (p. 621)......	3·4	8	Bromyrite (p. 397)....	5·8–6	2–3
Danalite (p. 504).....	3·43	5·5–6	**Cuprite** (p. 410).......	5·85–6·15	3·5–4
Hauerite (p. 378).....	3·46	4	**Eulytite** (p. 504).......	6·11	4·5
Diamond (p. 345).....	3·52	10	Bunsenite (p. 411).....	6·4	5·5
Yttrofluorite (p. 399)..	3·55	4·5	Monimolite (p. 593)...	6·58;7·29	5–6
Spinel (p. 419).......	3·5–4·1	8	Eglestonite (p. 401)....	8·3	2–3
Periclase (p. 411).....	3·67	6	Mosesite (p. 402)......		3

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* Some pseudo-isometric species are here included. Species with submetallic luster are placed under B, but some species are included in both lists.

B. Luster Metallic (and Submetallic).

	Specific Gravity.	Hardness.
Hauerite (p. 378)	3·46	4
Sphalerite (p. 367)	3·9–4·1	3·5–4
Alabandite (p. 369)	3·95–4·04	3·5–4
Cubanite (p. 374)	4·0–4·1	4
Dysanalyte (p. 586)	4·13	5–6
Chromite (p. 423)	4·3–4·57	5·5
Villamaninite (p. 379)	4·4	4·5
Tennantite (p. 391)	4·4–4·49	3–4
Tetrahedrite (p. 390)	4·4–5·1	3–4
Magnesioferrite (p. 420)	4·57–4·65	6–6·5
Polydymite (p. 373)	4·5–4·8	4·5
Cobaltnickelpyrite (p. 378)	4·71	5
Jacobsite (p. 421)	4·75	6
Sychnodymite (p. 373)	4·76	
Linnæite (p. 374)	4·8–5	5·5
Carrollite (p. 374)	4·85	5·5
Bixbyite (p. 425)	4·95	6–6·5
Pentlandite (p. 369)	5·0	3·5–4
Pyrite (p. 377)	4·95–5·10	6–6·5
Franklinite (p. 420)	5·07–5·22	6–6·5
Magnetite (p. 420)	5·18	6–6·5
Bornite (p. 374)	4·9–5·4	3
Gersdorffite (p. 379)	5·6–6·2	5·5
Cuprite (p. 410)	5·85–6·15	3·5–4
Brongniardite (p. 387)	5·95	3·5
Corynite (p. 379)	5·95–6·03	4·5–5
Argyrodite (p. 391)	6·1–6·2	2·5
Cobaltite (p. 379)	6–6·3	5·5
Canfieldite (p. 394)	6·28	2·5–3
Ullmannite (p. 379)	6·2–6·7	5–5·5
Smaltite, Chloanthite (p. 378)	6·4–6·6	5·5–6
Skutterudite (p. 380)	6·7–6·86	6
Willyamite (p. 379)	6·87	5·5
Polyargyrite (p. 562)	6·97	2·5
Laurite (p. 379)	7·0	7·5
Argentite (p. 364)	7·2–7·36	2–2·5
Iron (p. 356)	7·3–7·8	4–5
Galena (p. 363)	7·4–7·6	2·5–3
Eucairite (p. 365)	7·5	2·5
Metacinnabarite (p. 369)	7·8	3
Clausthalite (p. 364)	7·6–8·8	2·5–3
Naumannite (p. 364)	8·0	2·5
Altaite (p. 364)	8·16	3
Tiemannite (p. 369)	8·2–8·5	2·5
Hessite (p. 365)	8·3–8·5	2·5–3
Copper (p. 353)	8·8–8·9	2·5–3
Uraninite (p. 623)	9–9·7	5·5
Thorianite (p. 624)	9·3	
Silver (p. 352)	10·1–11·1	2·5–3
Sperrylite (p. 379)	10·6	6–7
Lead (p. 354)	11·4	1·5
Palladium (p. 355)	11·3–11·8	4·5–5
Amalgam (p. 354)	13·7–14·1	3–3·5
Platinum (p. 355)	14–19	4–4·5
Gold (p. 350)	15·6–19·3	2·5–3
Iridium (p. 355)	22·6–22·8	6–7

II. CRYSTALLIZATION TETRAGONAL.

A. Luster Nonmetallic.

	Specific Gravity.	Hardness.		Specific Gravity.	Hardness.
Mellite (p. 645)	1·64	2–2·5	Hardystonite (p. 498)	3·4	3–4
Darapskite (p. 619)			**Torbernite** (p. 648)	3·4–3·6	2–2·5
Pinnoite (p. 622)	2·29		Trippkeite (p. 618)		
Apophyllite (p. 546)	2·3–2·4	4·5–5	**Octahedrite** (p. 428)	3·8–3·95	5·5–6
Löweite (p. 637)	2·38	2·5–3	**Rutile** (p. 427)	4·18–4·25	6–6·5
Ecdemite (p. 618)	6·9–7·1	2·5–3	**Xenotime** (p. 592)	4·45–4·56	4–5
Sarcolite (p. 518)	2·54–2·93	6	Powellite (p. 643)	4·53	3·5
Marialite (p. 518)	2·57	5·5–6	**Thorite** (p. 522)	4·4–5·4	4·5–5
Mizzonite (Dipyre), (p. 517)	2·62	5·5–6	Fergusonite (p. 588)	4·4–5·8	5·5–6
Wernerite (Scapolite), (p. 516)	2·66–2·73	5·5–6	**Zircon** (p. 520)	4·68–4·7	7·5
Meionite (p. 516)	2·70–2·74	5·5–6	Romeite (p. 618)	4·71	5·5–6
Edingtonite (p. 555)	2·70	4–4·5	Sipylite (p. 588)	4·89	6
Narsarsukite (p. 585)	2·7	7·0	Nasonite (p. 498)	5·4	4
Chiolite (p. 400)	2·84–2·99	3·5–4	Ganomalite (p. 498)	5·74	3
Soumansite (p. 614)	2·87	4·5	**Scheelite** (p. 642)	5·9–6·1	4·5–5
Melilite (p. 518)	2·9–3·1	5	**Phosgenite** (p. 450)	6–6·09	2·75–3
Gehlenite (p. 518)	2·9–3·1	5·5–6	**Calomel** (p. 395)	6·48	1–2
Meliphanite (p. 496)	3·01	5–5·5	**Wulfenite** (p. 643)	6·7–7·0	2·75–3
Sellaite (p. 399)	2·97–3·15	5	**Cassiterite** (p. 425)	6·8–7·1	6–7
Zeunerite (p. 616)	3·2	2–2·5	Matlockite (p. 401)	7·2	2·5–3
Pinnoite (p. 622)	3·27–3·37	3–4	Tapiolite (p. 590)	7·36–7·5	6
Vesuvianite (p. 519)	3·35–3·45	6·5	Larettoite (p. 401)	7·6	3
			Stolzite (p. 643)	7·87–8·13	2·75–3

B. Luster Metallic (and Submetallic).

Chalcopyrite (p. 374)	4·1–4·3	3·5–4	Polianite (p. 427)	4·84–5·0	6–6·5
STANNITE (p. 394)	4·3–4·5	4	Reinite (p. 644)	6–6·4	4
Rutile (p. 427)	4·18–4·25;5·2	6–6·5	Hauchecornite (p. 372)	6·4	5
Fergusonite (p. 588)	4·4–5·8	5·5–6	Tapiolite (p. 590)	7·36–7·5	6
Hausmannite (p. 424)	4·7–4·86	5–5·5	Maucherite (p. 362)	7·83	5
Braunite (p. 425)	4·75–4·82	6–6·5	Plattnerite (p. 428)	8·5	5–5·5

III. CRYSTALLIZATION HEXAGONAL.*

Rhombohedral species are distinguished by a letter R.

A. LUSTER NONMETALLIC.

	Specific Gravity.	Hardness.
Ice (p. 411)	0·9	1·5
Cyprusite? (p. 639)	1·75	2
Ettringite (p. 640)	1·75	2–2·5
Thaumasite (p. 581)	1·88	3·5
Koenenite (p. 401) R	2·0	2·0
Gmelinite (p. 554) R.	2·04–2·17	4·5
Pyroaurite (p. 455) R.	2·07	2–3
Coquimbite (p. 637) R.	2·09	2–2·5
Utahite (p. 639) R.		
Chabazite (p. 552) R.	2·08–2·16	4–5
Levynite (p. 554) R.	2·09–2·16	4–4·5
Hydronephelite? (p. 558)	2·26	4·5–6
Soda niter (p. 619) R.	2·26	1·5–2
Tridymite (p. 407)	2·28–2·33	7
Rinneite (p. 399) R.	2·3	3
Brucite (p. 434) R.	2·38–2·4	2·5
Cancrinite (p. 501)	2·42–2·5	5–6
Microsommite (p. 501)	2·44	6
Kaliophilite (p. 501)	2·49	6
Carphosiderite? (p. 539) R.	2·50	4–4·5
Colerainite (p. 583)	2·51	2·5–3
Metavoltine (p. 639)	2·53	2·5
Chalcophyllite (p. 612) R	2·44–2·66	2
Nephelite (p. 499)	2·55–2·65	5·5–6
Hanksite (p. 631)	2·56	3–3·5
Ferronatrite (p. 638) R.	2·56	2
Milarite (p. 455)	2·57	5·5–6
Spodiophyllite (p. 572)	2·6	3–3·2
Aphthitalite (p. 624) R.	2·64	3–3·5
Quartz (p. 403) R.	2·65	7
Beryl (p. 495)	2·64–2·7;2·80	7·5–8
Eucryptite (p. 500)	2·67	
Alunite (p. 639) R.	2·67	3·5–4
Penninite (pseu.) (p. 570) R.	2·6–2·85	2·25
Calcite (p. 438) R.	2·71	3
Nepouite (p. 515)	2·5–3·2	2–2·5
Alumian (p. 632)	2·74	2–3
Catapleiite (p. 496)	2·8	6
Dolomite (p. 442) R.	2·8–2·9	3·5–4
Martinite (p. 611) R.	2·89	
Eudialyte (p. 496) R.	2.91–2·93	5–5·5
Ankerite (p. 443) R.	2·95–3·1	3·5–4
Phenacite (p. 514) R.	2·97–3·0	7·5–8
Tourmaline (p. 540) R.	2·98–3·20	7–7·5
Bityite (p. 558)	3·0	5·5
Magnesite (p. 443) R.	3·0–3·12	3·5–4·5
Pyrosmalite (p. 515) R.	3·06–3·19	4–4·5
Friedelite (p. 515) R.	3·07	4–5
Podolite (p. 618)	3·1	
Spangolite (p. 631) R.	3·14	2
Apatite (p. 595)	3·17–3·23	5
Harttite (p. 601)	3·2	4·5–5
Jarosite (p. 640) R.	3·20	2·5–3·5
Raimondite (p. 639)	3·20	3
Wilkeite (p. 597)	3·23	5

	Specific Gravity.	Hardness.
Hamlinite (p. 601) R.	3·23	4·5
Pyrochroite (p. 435) R.	3·26	2·5
Jeremejevite (p. 620)	3·28	6·5
Dioptase (p. 515) R.	3·28–3·35	5
Svanbergite (p. 618) R.	3·30	5
Cronstedtite (p. 571) R.	3·35	3·5
Hematolite (p. 606) R.	3·35	3·5
Connellite (p. 631)	3·36	3
Mesitite (p. 443) R.	3·33–3·42	3·5–4
Rhodochrosite (444) R.	3·45–3·60	3·5–4·5
Svabite (p. 598)	3·52	5
Fermorite (p. 597)	3·52	5
Florencite (p. 601) R.	3·58	5
Benitoite (p. 585)	3·6	6·2–6·5
Siderite (p. 443) R.	3·83–3·88	3·5–4
Rhabdophanite (p. 609) R.	3·94–4·01	3·5
Wurtzite (p. 371)	3·98	3·5–4
Corundum (p. 413) R.	3·95–4·10	9
Willemite (p. 513) R.	3·94–4·19	5·5
Geikielite (p. 586) R.	4·0	6·0
Sphærocobaltite (446) R	4·02–4·13	4
Melanocerite (p. 496) R.	4·13	5–6
Tritomite (p. 496) R.	4·20	5·5
Nordenskiöldine (620) R	4·20	5·5–6
Caryocerite (p. 496) R.	4·29	5–6
Parisite (p. 621)	4·36	4·5
Smithsonite (p. 445) R.	4·30–4·45	5
Beudantite (p. 618) R.	4–4·3	3·5–4·5
Plumbogummite? (p. 601)	4–4·9	4–5
Britholite (p. 580)	4·4	5·5
Cappelenite (p. 496)	4·41	6–6·5
Pyrophanite (p. 418)	4·5	5
Hinsdalite (p. 618)	4·65	4·5
Molybdophyllite (p. 498)	4·7	3–4
Bastnäsite (p. 449)	4·9	4·5
GREENOCKITE (p. 371)	4·9–5·0	3–3·5
Hematite (p. 415) R.	4·9–5·3	5·5–6·5
Xanthoconite (p. 393) R	5–5·2	2
Zincite (p. 411)	5·4–5·7	4–4·5
Bellite (p. 631)	5·5	2·5
PROUSTITE, (p. 389) R.	5·6	2–2·5
Iodyrite (p. 397)	5·6–5·7	1–1·5
Fluocerite (p. 399)	5·7–5·9	4
PYRARGYRITE (p. 389) R	5·85	2·5
Penfieldite (p. 401)		
Barysilite (p. 498)	6·11	3
Tysonite (p. 399)	6·13	4·5–5
Pyromorphite (p. 597)	6·5–7·1	3·5–4
Vanadinite (p. 598)	6·66–6·86	3
Mimetite (p. 598)	7·0–7·25	3·5
Kleinite (p. 395)	8·0	3·5
Cinnabar (p. 370) R.	8·08–8·2	2–2·5

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* Some pseudo-hexagonal species are included.

B. Luster Metallic (and Submetallic).

	Specific Gravity.	Hardness.		Specific Gravity.	Hardness.
Graphite (p. 347) R	2·1–2·2	1–1·5	**Pyrargyrite** (p. 389) R	5·85	2·5
Chalcophanite (p. 435) R	3·91	2·5	Tellurium (p. 349) R	6·1–6·3	2–2·5
Ilmenite (p. 417) R	4·5–5	5–6	Allemontite (p. 349) R	6·2	3·5
Covellite (p. 371)	4·6	1·5–2	Antimony (p. 349) R	6·7	3–3·5
Pyrrhotite (p. 373)	4·6	3·5–4·5	Tetradymite (p. 360) R	7·2–7·6	1·5–2
Molybdenite (p. 360)	4·7–4·8	1–1·5	**Niccolite** (p. 372)	7·3–7·67	5–5·5
Langbanite (p. 539)	4·92	6·5	Breithauptite (p. 372)	7·54	5·5
Xanthoconite (p. 393)	5		Platynite (p. 385) R	8	2–3
Hematite (p. 415) R	5·2–5·3	5·5–6·5	**Cinnabar** (p. 370) R	8·0–8·2	2–2·5
Senaite (p. 418) R	5·3	6	Bismuth (p. 349) R	9·7–9·8	2–2·5
Millerite (p. 372) R	5·3–5·65	3–3·5	**Iridosmine** (p. 355) R	19·3–21·1	6–7
Arsenic (p. 348) R	5·6–5·7	3·5			

IV. CRYSTALLIZATION ORTHORHOMBIC.

A. Luster Nonmetallic.

Teschemacherite (p.450)	1·45	1·5	Edingtonite (p. 555)	2·69	4–4·5
Thermonatrite (p. 452)	1·5–1·6	1–1·5	Hillebrandite (p. 546)	2·7	5·5
Carnallite (p. 401)	1·6	1–1·5	Hopeite (p. 607)	2·76	2·5–3
Struvite (p. 606)	1·65–1·7	2	Phosphosiderite (p.610)	2·76	3·75
Epsomite (p. 635)	1·75	2–2·5	**Talc** (p. 575)	2·7–2·8	1–1·5
Mascagnite (p. 624)	1·77	2–2·5	Beryllonite (p. 595)	2·84	5·5–6
Nesquehonite (p. 452)	1·84	2·5	Haidingerite (p. 610)	2·85	1·5–2·5
Goslarite (p. 635)	2·0	2–2·25	Strengite (p. 610)	2·87	3–4
Erionite (p. 558)	1·99		**Prehnite** (p. 534)	2·8–2·95	6–6·5
Morenosite (p. 635)	1·9–2·1	2–2·5	Guarinite (p. 525)	2·9–3·3	6·5
Sulphur (p. 347)	2·07	1·5–2·5	**Anhydrite** (p. 629)	2·90–2·98	3–3·5
Lindackerite (p. 618)	2·0–2·5	2–2·5	**Aragonite** (p. 446)	2·94	3·5–4
Newberyite (p. 611)	2·10	3–3·5	Spodiosite? (p. 600)	2·94	4
Stellerite (p. 558)	2·12	3·5–4	Leucophanite (p. 496)	2·96	5
Niter (p. 619)	2·09–2·14	2	Cebollite (p. 518)	2·96	5·0
Sideronatrite (p. 639)	2·15	2–2·5	**Danburite** (p. 522)	2·97–3·02	7–7·25
Epidesmine (p. 558)	2·16		Bementite (p. 582)	2·98	
Fluellite (p. 402)	2·17	3	Hopeite (p. 607)	3·0–3·1	3·2
Natrolite (p. 556)	2·20–2·25	5–5·5	Tyrolite (p. 612)	3·0–3·1	1·5
Okenite? (p. 546)	2·28	4–5·5	Harstigite (p. 535)	3·05	5·5
Felsöbanyite (p. 639)	2·33	1·5	Reddingite (p. 607)	3·10	3–3·5
Thomsonite (p. 557)	2·3–2·4	5–5·5	Lawsonite (p. 540)	3·08	7·5–8
Wavellite (p. 612)	2·33	3·5–4	Grothine (p. 545)	3·09	
Hambergite (p. 620)	2·35	7·5	**Humite** (p. 536)	3·1–3·2	6–6·5
Pirssonite (p. 452)	2·35	3·35	**Anthophyllite** (p. 486)	3·1–3·2	5·5–6
Sulfoborite (p. 623)	2·38–2·45	4	**Andalusite** (p. 524)	3·16–3·2	7·5
Dawsonite (p. 452)	2·40		**Enstatite** (p. 472)	3·15–3·3	5·5
Fischerite (p. 613)	2·46	5	**Autunite** (p. 616)	3·05–3·19	2–2·5
Peganite (p. 613)	2·50	3–3·5	Monticellite (p. 513)	3·03–3·25	5–5·5
Variscite (p. 610)		4	Eosphorite (p. 615)	3·11–3·15	5
Lucinite (p. 610)	2·52	5	Childrenite (p. 615)	3·18–3·24	4·5–5
Elpidite (p. 496)	2·52–2·59	6·5–7	**Sillimanite** (p. 526)	3·24	6–7
Howlite? (p. 621)	2·55	3·5	**Scorodite** (p. 609)	3·1–3·3	3·5–4
Bertrandite (p. 539)	2·6	6–7	Lossenite (p. 619)		
Lanthanite (p. 453)	2·6	2·5–3	**Forsterite** (p. 513)	3·2–3·33	6–7
Iolite (p. 497)	2·6–2·66	7–7·5	Dumortierite (p. 543)	3·26	7
Thenardite (p. 624)	2·68–2·69	2–3	Kornerupine (p. 544)	3·27	6·5

A. LUSTER NONMETALLIC

	Specific Gravity.	Hardness.		Specific Gravity.	Hardness.
Zoisite (p. 530)	3·25–3·37	6–6·5	Barylite (p. 498)	4·03	7
Dufrenite (p. 605)	3·23–3·4	3·5–4	**Tephroite** (p. 513)	4–4·12	5·5–6
Chrysolite (p. 511)	3·27–3·37	6·5–7	Carminite (p. 594)	4·105	2·5
Warwickite (p. 621)	3·35	3–4	Ampangabéite (p. 591)	3·97–4·29	4·0
Euchroite (p. 611)	3·39	3·5–4	Fayalite (p. 513)	4–4·14	6·5
Astrophyllite (p. 585)	3·3–3·4	3	Retzian (p. 606)	4·15	4
Diaspore (p. 431)	3·3–3·5	6·5–7	Olivenite (p. 603)	4·1–4·4	3
Lorenzenite (p. 586)	3·4	6·0	Hulsite (p. 622)	4·3	3
Purpurite (p. 610)	3·4	4–4·5	**Witherite** (p. 447)	4·3–4·35	3–3·75
Natrophilite (p. 594)	3·41	4·5–5	Adamite (p. 604)	4·34–4·35	3·5
Cenosite (p. 580)	3·41	5·5	Pseudobrookite (p. 424)	4·4–5	
Gerhardtite (p. 619)	3·43	2	**Barite** (p. 625)	4·5	2·5–3·5
Hypersthene (p. 473)	3·4–3·5	5·5	Derbylite (p. 618)	4·53	5
Uranospinite (p. 617)	3·45	2–3	Euxenite (p. 591)	4·6–5	6·5
Guarinite (p. 525)	3·49	6	Yttrocrasite (p. 586)	4·8	5·5–6
Calamine (p. 539)	3·4–3·5	4·5–5	Cerite (p. 540)	4·86	5·5
Lithiophilite (p. 594)	3·42–3·56	4·5–5	Blomstrandine (p. 591)	4·8–4·9	
Topaz (p. 523)	3·4–3·65	8	Æschynite (p. 591)	4·93;5·17	5–6
Langite (p. 638)	3·49	2·5–3	Polycrase (p. 591)	4·97–5·04	5–6
Erikite (p. 580)	3·5	5·5	Cotunnite (p. 399)	5·24–5·8	2
Uranocircite (p. 617)	3·53		Pyrobelonite (p. 604)	5·38	3·5
Triphylite (p. 594)	3·52–3·55	4·5–5	Valentinite (p. 410)	5·57	2·5–3
Epididymite (p. 455)	3·55	5·5	**Samarskite** (p. 590)	5·6–5·8	5–6
Mazapilite (p. 615)	3·57	4·5	Yttrotantalite (p. 590)	5·5–5·9	5–5·5
Thortveite (p. 529)	3·57	6–7	Melanotekite (p. 539)	5·7	6·5
Hemafibrite (p. 611)	3·50–3·65	3	Annerödite (p. 591)	5·7	6
Chrysoberyl (p. 423)	3·5–3·8	8·5	Phœnicochroite?		
Aurichalcite (p. 451)	3·54–3·64		(p. 630)	5·75	3–3·5
Ardennite (p. 539)	3·62	6–7	Tellurite (p. 410)	5·9	2
Libethenite (p. 603)	3·6–3·8	4	Descloizite (p. 604)	5·9–6·2	3·5
Staurolite (p. 543)	3·65–3·75	7–7·5	Tsumebite (p. 604)	6·1	3·5
Strontianite (p. 447)	3·68–3·71	3·5–4	Kentrolite (p. 539)	6·19	5
Bromlite (p. 447)	3·72	4–4·5	**Anglesite** (p. 628)	6·12–6·39	2·75–3
ATACAMITE (p. 400)	3·76	3–3·5	Pucherite (p. 594)	6·25	4
Uranophane (p. 581)	3·81–3·9	2·3	**Caledonite** (p. 632)	6·4	2·5–3
Flinkite (p. 606)	3·87	4–4·5	Daviesite (p. 401)		
Serpierite (p. 638)			Laurionite (p. 401)		3–3·5
Brochantite (p. 632)	3·91	3·5–4	**Cerussite** (p. 448)	6·46–6·57	3–3·5
Brookite (p. 429)	3·87–4·07	5·5–6	Nadorite (p. 618)	7·02	3·5–4
Pinakiolite (p. 620)	3·88	6	Ochrolite (p. 618)		
Ancylite (p. 449)	3·9	4·5	Mendipite (p. 401)	7–7·1	2·5–3
Celestite (p. 627)	3·95–3·97	3–3·5	Georgiadésite (p. 594)	7·1	3·5
Ludwigite (p. 620)	3·91–4·02	5	Stibiotantalite (p. 590)	6·0–7·4	5·5
Knebelite (p. 513)	3·9–4·1	6·5	Montroydite (p. 412)		1·5–2

B. LUSTER METALLIC (AND SUBMETALLIC).

Brookite (p. 429)	3·87–4·07	5·5–6	**Stibnite** (p. 358)	4·5–4·6	2
Ilvaite (p. 538)	4·0–4·05	5·5–6	Famatinite (p. 393)	4·57	3·5
Göthite (p. 431)	4·0–4·4	5–5·5	Klaprotholite (p. 386)	4·6	2·5
Sternbergite (p. 367)	4·1–4·2	1–1·5	Hutchinsonite (p. 386)	4·6	1·5–2
Manganite (p. 432)	4·2–4·4	4	Euxenite (p. 591)	4·6–5	6·5
Enargite (p. 393)	4·43–4·45	3	Chalmersite (p. 366)	4·7	3·5
Wittichenite (p. 388)	4·5		Chalcostibite (p. 386)	4·75–5	3–4

B. Luster Metallic (and Submetallic).

	Specific Gravity.	Hardness.		Specific Gravity.	Hardness.
Pyrolusite (p. 430)	4·73–4·86	2–2·5	Kentrolite (p. 539)	6·19	5
Polymignite (p. 591)	4·77–4·85	6·5	Aikinite (p. 388)	6·1–6·8	2–2·5
Stylotypite (p. 388)	4·8	3	Stromeyerite (p. 366)	6·15–6·3	2·5–3
Marcasite (p. 380)	4·85–4·9	6–6·5	STEPHANITE (p. 392)	6·2–6·3	2–2·5
Æschynite (p. 591)	4·93; 5·17	5–6	Guanajuatite (p. 359)	6·25–6·6	2·5–3·5
Urbanite (p. 477)	5·3	3·5	Mullanite (p. 388)	6·3	3·5
ZINKENITE (p. 385)	5·3–5·35	3–3·5	Geocronite (p. 392)	6·3–6·45	2·5
Andorite (p. 385)	5·34		Wolfachite (p. 382)	6·37	4·5–5
Sartorite (p. 385)	5·39	3	Emplectite (p. 386)	6·3–6·5	2
Columbite (p. 588)	5·36–6·0	6	Teallite (p. 394)	6·4	1–2
Rathite (p. 386)	5·4	3	Meneghinite (p. 391)	6·4	2·5
DUFRENOYSITE (p. 387)	5·55	3	BISMUTHINITE (p. 359)	6·4–6·5	2
Chalcocite (p. 366)	5·5–5·8	2·5–3	Schapbachite (p. 387)	6·43	3·5
Yttrotantalite (p. 590)	5.5–5·9	5–5·5	Alloclasite (p. 382)	6·6	4·5
Annerödite (p. 591)	5·7	6	Cosalite (p. 387)	6·4–6·75	2·5–3
Melanotekite (p. 539)	5·7	6·5	**Nagyagite** (p. 383)	6·85–7·2	1–1·5
Bournonite (p. 388)	5·7–5·9	2·5–3	Rammelsbergite (p. 382)	6·9–7·2	5·5–6
Seligmanite (p. 388)		3	Safflorite (p. 382)	6·9–7·3	4·5–5
BOULANGERITE (p. 387)	5·75–6·0	2·5–3	**Tantalite** (p. 588)	7–7·3	6
Hielmite (p. 591)	5·82	5	Löllingite (p. 381)	7·0–7·4	5–5·5
Diaphorite (p. 387)	5·9	2·5–3	Acanthite (p. 367)	7·2–7·3	2–2·5
Glaucodot (p. 382)	5·9–6·0	5	Krennerite (p. 383)	8·35	
Arsenopyrite (p. 381)	5·9–6·2	5·5–6	Dyscrasite (p. 361)	9·4–9·8	3·5–4

V. CRYSTALLIZATION MONOCLINIC.

A. Luster Nonmetallic.

Natron (p. 452)	1·44	1–1·5	Trona (p. 453)	2·12	2·5–3
Mirabilite (p. 632)	1·48	1·5–2	Picromerite (p. 637)	2·1–2·2	
Whewellite (p. 641)		2·5	Castanite (p. 639)	2·12	3
Stercorite (p. 611)	1·615	2	Quenstedtite (p. 637)	2·12	2·5
Aluminite (p. 639)	1·66	1–2	Heintzite (p. 622)	2·13	4–5
Alunogen (p. 638)	1·6–1·8	1·5–2	Hydromagnesite (p. 452)	2·16	3·5
Borax (p. 622)	1·69–1·72	2–2·5	**Stilbite** (p. 551)	2·16–2·20	3·5–4
Boussingaultite (p. 637)	1·70		**Scolecite** (p. 557)	2·16–2·4	5–5·5
Apjohnite? (p. 637)	1·78	1·5	Brushite (p. 611)	2·21	2–2·5
Fibroferrite? (p. 639)	1·84	2–2·5	**Heulandite** (p. 548)	2·18–2·22	3·5–4
Inyoite (p. 622)	1·87	2·0	Darapskite (p. 619)	2·20	2–3
Melanterite (p. 636)	1·90	2	**Phillipsite** (p. 550)	2·2	4–4·5
Halotrichite? (p. 637)	1·9–2·0		Mesolite (p. 557)	2·2–2·4	5
Pickeringite (p. 637)			**Blödite** (p. 637)	2·25	2·5
Hydroboracite (p. 623)	1·9–2·0	2	Epistilbite (p. 549)	2·25	4–4·5
Gay-Lussite (p. 452)	1·94	2–3	Gismondite (p. 552)	2·26	4·5
Kröhnkite (p. 638)	1·98	2·5	**Laumontite** (p. 552)	2·25–2·36	3·5–4
Artinite (p. 453)	2·0	2·0	Metabrushite (p. 611)	2·29	2·5–3
Diadochite (p. 618)	2·035	3	Wellsite (p. 549)	2·28–2·37	4–4·5
Botryogen (p. 639)	2·04–2·14	2–2·5	Natrochalcite (p. 638)	2·3	4·5
Mordenite (p. 548)	2·08	3–4	Griffithite (p. 572)	2·31	1·0
Kainite (p. 631)	2·07–2·19	2·5–3	**Gypsum** (p. 633)	2·31–2·33	1·5–2
Quetenite?. (p. 640)	2·08–2·14	3	Gibbsite (p. 435)	2·3–2·4	2·5–3·5
Copiapite (p. 638)	2·10	2·5	**Petalite** (p. 455)	2·39–2·46	6–6·5
Flokite (p. 552)	2·10	5	Colemanite (p. 621)	2·42	4–4·5

A. LUSTER NONMETALLIC.

	Specific Gravity.	Hardness.		Specific Gravity.	Hardness.
Hautefeuillite (p. 608)	2·435	2·5	Cabrerite (p. 609)	2·96	2
Brewsterite (p. 549)	2·45	5	Beraunite (p. 615)	2·98.	
Harmotome (p. 550)	2·44–2·5	4·5	Herderite (p. 601)	2·99–3·01	5
Pascoite (p. 609)	2·46	2·5	**Margarite** (p. 566)	2·99–3·08	3·5–4·5
Ectropite (p. 582)	2·46	4	**Amphibole** (p. 487)	2·9–3·4	5–6
Hœrnesite (p. 608)	2·47	1	Leucosphenite (p. 585)	3·0	6·5
Wapplerite? (p. 611)	2·48	2–2·5	Fremontite (p. 602)	3·04	5·5
Serpentine (p. 573)	2·50–2·65	2·5–4	**Lazulite** (p. 605)	3·06	5–6
Calcioferrite (p. 615)	2·52–2·53	2·5	Wagnerite (p. 600)	3·07	5–5·5
Eudidymite (p. 455)	2·55	6	Szomolnokite (p. 633)	3·08	
Orthoclase (p. 457)	2·57	6	Xanthophyllite (p. 567)	3·09	4·6
Kieserite (p. 633)	2·57	3–3·5	Seybertite (p. 566)	3–3·1	4–5
Vivianite (p. 608)	2·58–2·68	1·5–2	Lepidomelane (p. 565)	3·0–3·2	3
Syngenite (p. 636)	2·60	2·5	Bassetite (p. 617)	3·10	
Kaolinite (p. 578)	2·6–2·63	2–2·5	Köttigite (p. 609)	3·1	2·5–3
Pharmacolite (p. 610)	2·64–2·73	2–2·5	**Euclase** (p. 529)	3·10	7·5
Clinochlore (p. 569)	2·65–2·78	2–2·5	**Glaucophane** (p. 492)	3·10–3·11	6–6·5
Pectolite (p. 483)	2·68–2·78	5	Ludlamite (p. 614)	3·12	3–4
Augelite (p. 614)	2·7	4·5–5	Spencerite (p. 612)	3·12	2·7
Bavenite (p. 558)	2·7	5·5	Lacroixite (p. 601)	3·13	4·1
Didymolite (p. 497)	2·71	4–5	Herrengrundite (p. 638)	3·13	2·5
Creedite (p. 402)	2·73	3–5	Churchite? (p. 609)	3·14	3–3·5
Glauberite (p. 625)	2·7–2·85	2·5–3	**Chondrodite** (p. 536)	3·1–3·2	6–6·5
Vilateite (p. 610)	2·75	3–4	**Clinohumite** (p. 536)	3·1–3·2	6–6·5
Polyhalite? (p. 637)	2·77	2·5–3	Prolectite (p. 538)		
Muscovite (p. 560)	2·76–3	2–2·5	**Spodumene** (p. 480)	3·13–3·2	6·5–7
Lepidolite (p. 562)	2·8–2·9	2·5–4	Hureaulite (p. 611)	3·185	5
Biotite (p. 563)	2·7–3·1	2·5–3	Johannite (p. 640)	3·199	2–2·5
Phlogopite (p. 565)	2·78–2·85	2·5–3	Palaite (p. 607)	3·2	
Prochlorite (p. 571)	2·78–2·96	1–2	Hibbenite (p. 612)	3·21	3·7
Hyalophane (p. 460)	2·805	6–6·5	**Pyroxene** (p. 474)	3·3–3·6	5–6
Ganophyllite (p. 546)	2·84	4–4·5	Neptunite (p. 585)	3·23	5–6
Zinnwaldite (p. 563)	2·82–3·20	2·5–3	Johnstrupite (p. 585)	3·29	
Cuspidine (p. 535)	2·86	5–6	**Epidote** (p. 531)	3·25–3·5	6–7
Minguétite (p. 572)	2·86		Rosenbuschite (p. 483)	3·3	5–6
Liroconite (p. 615)	2·88	2–2·5	Trögerite (p. 617)	3·3	
Wollastonite (p. 482)	2·8–2·9	4·5–5	Ottrelite? (p. 567)	3·3	6–7
Pyrophyllite (p. 579)	2·8–2·9	1–2	Gilpinite (p. 640)	73·3	2
Prosopite (p. 402)	2·89	4·5	Clinohedrite (p. 540)	3·33	5·5
Epistolite (p. 592)	2·9	1–1·5	**Jadeite** (p. 479)	3·33–3·35	6·5–7
Corundophilite (p. 571)	2·90	2·5	Celsian (p. 460)	3·37	6–6·5
Stilpnomelane (p. 572)	2·77–2;96	3·4	Homilite (p. 529)	3·38	5
Tæniolite (p. 565)	2·9	2·5–3	Dickinsonite (p. 607)	3·34	3·5–4
Custerite (p. 497)	2·91	5·0	**Piedmontite** (p. 532)	3·40	6·5
Isoclasite? (p. 611)	2·92	1·5	Wöhlerite (p. 484)	3·41–3·44	5·5–6
Roscoelite (p. 565)	2·92–2·94		Sapphirine (p. 544)	3·42–3·48	7·5
Carpholite (p. 540)	2·93	5–5·5	Riebeckite (p. 493)	3·43	
Datolite (p. 527)	2·9–3·0	5–5·5	Fillowite (p. 607)	3·43	4·5
Pachnolite (p. 402)	2·93–3	3	Triplite (p. 600)	3·44–3·8	4–5·5
Thomsenolite (p. 402)	2·93–3	2–3	ORPIMENT (p. 357)	3·4–3·5	1·5–2
Cryolite (p. 399)	2·95–3	2·5	Rinkite (p. 585)	3·46	5
Mosandrite (p. 585)	2·93–3	4	**Arfvedsonite** (p. 494)	3·44–3·45	6
Jezekite (p. 601)	2·94	4·5	Synadelphite (p. 606)	3·45–3·50	4·5
Erythrite (p. 608)	2·95	1·5–2·5	**Titanite** (p. 583)	3·4–3·65	5–5·5
Symplesite (p. 608)	2·96	2·5	**Acmite** (p. 479)	3·5–3·55	6–6·5

A. LUSTER NONMETALLIC.

	Specific Gravity.	Hardness.		Specific Gravity.	Hardness.
Veszelyite (p. 612).....	3·53	3·5–4	Dihydrite (p. 605).....	4–4·4	4·5–5
Låvenite (p. 484)......	3·51–3·55	6	Sarkinite (p. 601)......	4·18	4–5
Chloritoid? (p. 567)....	3·52–3·57	6·5	Pyrostilpnite (p. 390) ..	4·2	2
Keilhauite (p. 585).....	3·52–3·77	6·5	Thalénite (p. 529)......	4·2	6·5
Graftonite (p. 594).....	3·7	5	Clinoclasite (p. 604)....	4·19–4·36	2·5–3
Dietzeite (p. 619)......	3·70	3–4	Kermesite (p. 383).....	4·5–4·6	1–1·5
Triploidite (p. 601).....	3·7	4·5–5	Catoptrite (p. 618).....	4·5	5·5
REALGAR (p. 357)......	3·6	1·5–2	Lautarite (p. 619)......	4·59	
Barytocalcite (p. 449)..	3·65	4	**Monazite** (p. 593)......	4·9–5·3	5–5·5
Adelite, Tilasite (p. 601)	3·74	5	**Linarite** (p. 632).......	5·3–5·45	2·5
Chalcomenite (p. 641)..	3·76		Lorandite (p. 386).....	5·53	2–2·5
Azurite (p. 451).......	3·77–3·83	3·5–4	Baddeleyite (p. 428)....	5·5;6·025	6·5
Leucophœnicite (p. 538)	3·8	5·5–6	Vauquelinite (p. 630)...	5·8–6·1	2·5–3
Allactite (p. 606).......	3·83–3·85	4·5	**Crocoite** (p. 630).......	5·9–6·1	2·5–3
Allanite (p. 533)........	3·5–4·2	5·5–6	Agricolite (p. 510)......	6·0?	
Claudetite (p. 409).....	3·85–4·15	2·5	**Tenorite** (p. 412).......	5·8–6·25	3–4
Hodgkinsonite (p. 582) .	3·91	4·5–5	**Leadhillite** (p. 631).....	6·26–6·44	2·5
Malachite (p. 450).....	3·9–4·03	3·5–4	**Lanarkite** (p. 632)......	6·3–6·4	2–2·5
Durangite (p. 601).....	3·94–4·07	5	Atelestite (p. 606)......	6·4	3–4·5
Hancockite (p. 533)....	4·0	6–7	Alamosite (p. 483).....	6·5	4·5
Partschinite (p. 510)...	4·0	6·5–7	Fiedlerite (p. 401)......		
Gadolinite (p. 529).....	4·0–4·5	6·5–7	**Hübnerite** (p. 642).....	7·2–7·5	5–5·5
Barylite (p. 498).......	4·03	7	Raspite (p. 643)........		
Tagilite (p. 612).......	4·08	3–4	Terlinguaite (p. 401)...	8·7	2–3
Barthite (p. 612).......	4·19	3			

B. LUSTER METALLIC (AND SUBMETALLIC).

Baumhauerite (p. 386) .	3·3	3	Semseyite (p. 387).....	5·95	2–3
Allanite (p. 533).......	3·5–4·2	5·5–6	POLYBASITE (p. 392)....	6·0–6·2	2–3
Arizonite (p. 418).....	4·25	5·5	Pearceite (p. 393)......	6·15	3
Crednerite (p. 424).....	4·9–5·1	4·5	FREIESLEBENITE (p. 387)............	6·2–6·4	2–2·5
Smithite (p. 386).......	4·9	1·5–2	Jordanite (p. 391)......	6·39	3
MIARGYRITE (p. 386)..	5·1–5·3	2–2·5	**Wolframite** (p. 641)....	7·2–7·5	5–5·5
PLAGIONITE (p. 387)...	5·4	2·5	SYLVANITE (p. 382)....	7·9–8·3	1·5–2
JAMESONITE (p. 386)...	5·5–6·0	2·3	CALAVERITE (p. 383)...	9	2·5
Rittingerite (p. 393)....	5·63	2–2·5			

VI. CRYSTALLIZATION TRICLINIC.

A. Luster Nonmetallic.

Plag

	Specific Gravity.	Hardness.		Specific Gravity.	Hardness.
Sassolite (p. 435).......	1·48	1	Inesite (p. 546)........	3·03	6
Lansfordite (p. 453)....	1·54	2·5	**Amblygonite** (p. 602)...	3·01–3·09	6
Hannayite (p. 611).....	1·89		Fairfieldite (p. 607)....	3·10	3·5
Amarantite (p. 639)....	2·11	2·5	Messelite (p. 607)......		3·5
Meyerhofferite (p. 622).	2·12	2	Chalcosiderite (p. 616) .	3·11	4·5
Chalcanthite (p. 636)...	2·12–2·30	2·5	**Axinite** (p. 534)........	3·27	6·5–7
Römerite (p. 638)......	2·17	3–3·5	Hiortdahlite (p. 485)...	3·27	5–5·6
Ussingite (p. 470)......	2·5	6–7	Parahopeite (p. 607) ...	3·3	3·7
Microcline (p. 460).....	2·54–2·57	6–6·5	Babingtonite (p. 485) ..	3·35–3·37	5·5–6
Anorthoclase (p. 461) ..	2·57–2·60	6	Celsian (p. 460)........	3·37	6–6·5
Albite (p. 464).........	2·62–2·65	6–6·5	**Rhodonite** (p. 484).....	3·4–3·68	5·5–6·5
Oligoclase (p. 466).....	2·65–2·67	6–6·5	Trimerite (p. 515)......	3·47	6–7
Anemousite (p. 468)....	2·68		Chloritoid? (p. 567)....	3·52–3·57	6·5
Andesine (p. 466)......	2·68–2·69	6–6·5	Roselite (p. 607).......	3·5–3·6	3·5
Labradorite (p. 466)....	2·70–2·72	6–6·5	**Cyanite** (p. 526)........	3·56–3·67	5–7·25
Anorthite (p. 467)......	2·74–2·76	6–6·5	Brandtite (p. 607).....	3·67	5–5·5
Turquois (p. 613)......	2·6–2·83	5–6	Pyroxmangite (p. 485)..	3·8	5·5–6
Monetite (p. 606)......	2·75	3·5	Ænigmatite (p. 494)....	3·85	
Anapaite (p. 607)......	2·8	3·5	Margarosanite (p. 498) .	3·99	2·5–3
Stewartite (p. 607).....	2·94		Tarbuttite (p. 604).....	4·1	3·7
Schizolite (p. 483)......	3·0–31	5–5·5	Walpurgite? (p. 617)...	5·76	3·5

TABLE III. CRYSTALLINE HABIT.

I. ISOMETRIC SYSTEM.

In the following lists some species are enumerated whose crystalline habit is often so marked as to be a distinctive character.

Cubes. — Metallic Luster: Galena; Pyrite.

Nonmetallic Luster: Fluorite; Cuprite (at times elongated into capillary forms), Cerargyrite; Halite; Sylvite; Boracite; Pharmacosiderite. Also Percylite; Perovskite.

Cube-like forms occur with the following: Apophyllite (tetragonal); Cryolite (monoclinic). Also with the *rhombohedral* species: Chabazite: Alunite; Calcite; rarely Quartz and Hematite.

Octahedrons. — Metallic and Submetallic Luster: Magnetite; Franklinite; Chromite; Uraninite. Also sometimes, Galena; Pyrite; Linnæite; Dysanalyte.

Nonmetallic Luster: Spinel (incl. Hercynite and Gahnite); Cuprite; Diamond; Pyrochlore and Microlite; Ralstonite; Periclase; Alum.

Forms somewhat resembling regular octahedrons occur with some tetragonal species, as Braunite; Hausmannite; Chalcopyrite; Zircon; etc.; also with some *rhombohedral* species, as Dolomite.

Dodecahedrons. — Metallic Luster: Magnetite; Amalgam.

Nonmetallic Luster: Garnet; Cuprite; Sodalite.

Tetrahexahedrons. — Native Copper; Fluorite.

Trapezohedrons. — Nonmetallic Luster: Garnet; Leucite; Analcite.

Pyritohedrons. — Metallic Luster: Pyrite; Cobaltite. Also Gersdorffite; Hauerite (submetallic).

Tetrahedrons. — Metallic Luster: Tetrahedrite.

Nonmetallic Luster: Sphalerite; Boracite; Helvite; Eulytite; Diamond; Zunyite.

The tetragonal sphenoids of Chalcopyrite sometimes closely resemble tetrahedrons.

II. TETRAGONAL SYSTEM.

Square Pyramids. — Submetallic Luster: Braunite; Hausmannite.

Nonmetallic Luster: Zircon; Wulfenite; Vesuvianite; Octahedrite; Xenotime.

Square Prisms. — Nonmetallic Luster: Zircon; Vesuvianite; Scapolites; Apophyllite; Phosgenite.

Square tabular crystals occur with Apophyllite; Wulfenite; Torbernite.

Prisms nearly square are noted with a number of *orthorhombic* species, e.g., Topaz; Andalusite; Danburite: also with the monoclinic Pyroxene ($100 \wedge 010 = 90°$, $110 \wedge 1\bar{1}0 = 87°$)

III. HEXAGONAL SYSTEM.

Hexagonal Prisms. — Nonmetallic Luster: Beryl; Apatite; Pyromorphite; Vanadinite; Mimetite (usually indistinct rounded forms). Also Nephelite; Milarite: Tysonite, and others.

Hexagonal prisms are also common with the *rhombohedral* species: Quartz; Calcite; Tourmaline; Willemite; Phenacite; Dioptase, etc. Again, with the Micas, etc. Numerous rare species could be included here.

Many *orthorhombic* (or *monoclinic*) species having a prismatic angle of about 60° (and 120°) simulate this form both in simple crystals and still more as the result of twinning. Thus, Aragonite; Strontianite; Leadhillite; Iolite. It is also to be noted that the *isometric* dodecahedron, e.g., of Garnet, has often the form of a hexagonal pyramid with trihedral terminations (cf. Fig. 470, p. 175).

Tabular hexagonal prisms are noted with various species. Thus, Metallic Luster: Graphite; Molybdenite; Hematite; Ilmenite; Pyrrhotite. Nonmetallic Luster: Tridymite.

Hexagonal Pyramids. — Apatite; Corundum (rhombohedral); Quartz (rhombohedral-trapezohedral): Hanksite.

This form is often simulated by various *orthorhombic* species, in part as the result of twinning. For example, Metallic Luster: Chalcocite; Stephanite; Polybasite; Jordanite; etc. Also Brookite.

Nonmetallic Luster: Witherite; Bromlite; Cerussite; Iolite.

Trigonal Prisms. — Tourmaline.

Rhombohedrons. — Angle 75° (and 105°): Calcite; Dolomite; Siderite; Rhodochrosite. Angle not far from 90°: Chabazite; Alunite; Calcite; also Quartz; Hematite.

Scalenohedrons. — Calcite and allied Carbonates; Proustite.

IV. ORTHORHOMBIC, MONOCLINIC AND TRICLINIC SYSTEMS.

Prismatic Crystals. — METALLIC LUSTER: Stibnite; Arsenopyrite; Bournonite; Manganite; Göthite, etc.

NONMETALLIC LUSTER: (*orthorhombic*) Topaz; Staurolite; Andalusite; Barite; Celestite; Danburite. Also (*monoclinic*) Pyroxene; Amphibole; Orthoclase, and many others. Epidote crystals are often prismatic in aspect (Fig. 894, p. 531).

Tabular Crystals. — Barite; Cerussite; Calamine; Diaspore; Wollastonite; Albite.

Acicular Crystals. — METALLIC LUSTER: Stibnite; Bismuthinite; Millerite; Jamesonite; Aikinite, and other species.

NONMETALLIC LUSTER: Pectolite; Natrolite; Scolecite; Thomsonite, and other Zeolites. Also Aragonite; Strontianite; less often Calcite. Also many other species.

Twin Crystals. — The habit of the twins occurring with many species is very characteristic. Reference is made to pp. 165 to 172 and the accompanying figures for a presentation of this subject.

TABLE IV. STRUCTURE OF MASSIVE MINERALS

Fibrous. — *Fibers separable:* Asbestus (amphibole); also the similar asbestiform variety of serpentine (chrysotile); Crocidolite (color blue).

Fibers not separable, chiefly straight: Anthophyllite; Calcite; Gypsum. Also Aragonite; Barite; Celestite; Anhydrite; Brucite; Enstatite; Wollastonite; Dufrenite; Vivianite. See also *Columnar* below.

Fibrous-Radiated. — Wavellite; Pectolite; Thomsonite; Natrolite; Stilbite, Scolecite; and other Zeolites; Göthite; Malachite.

Columnar. — METALLIC LUSTER: Stibnite; Hematite; Jamesonite; Zinkenite, etc.

NONMETALLIC LUSTER: Limonite; Göthite; Aragonite; Amphibole (tremolite, actinolite, etc.); Epidote; Zoisite; Tourmaline; Sillimanite; Natrolite and other Zeolites; Strontianite; Witherite; Topaz.

Cyanite has often a *bladed* structure.

Fibrous and columnar varieties pass into one another.

Lamellar-Stellate. — Gypsum; Pyrophyllite; Talc.

Foliated. — METALLIC LUSTER: Graphite; Molybdenite; Tetradymite; Sternbergite; Nagyagite.

NONMETALLIC LUSTER: Talc; Orpiment; Gypsum; Pyrophyllite; Serpentine; Gypsum.

Micaceous. — The Micas, p. 559: also the Brittle Micas, p. 566, and the Chlorites, p. 568. Also Brucite; Orpiment; Talc; Torbernite; Autunite.

Granular. — METALLIC LUSTER: Galena; Hematite; Magnetite. Many sulphides, sulpharsenites; etc., have varieties which are fine-granular to compact and impalpable.

NONMETALLIC LUSTER: Pyroxene (coccolite); Garnet; Calcite; Barite, etc.

Botryoidal, Mammillary, Reniform, etc. — METALLIC LUSTER: Hematite; Arsenic; Allemontite.

NONMETALLIC LUSTER: Malachite; Prehnite; Smithsonite; Calamine; Chalcedony; Hyalite; rarely Sphalerite, etc.

Stalactitic. — METALLIC LUSTER: Limonite; Psilomelane; Marcasite.

NONMETALLIC LUSTER: Calcite; Aragonite; Gibbsite; Chalcedony.

Granular Cleavable. — METALLIC LUSTER: Galena.

NONMETALLIC LUSTER: Calcite; Dolomite; Sphalerite; Fluorite.

Oölitic. — Calcite; Aragonite; Hematite.

Earthy. — NONMETALLIC LUSTER: Magnesite; piolite

TABLE V. PHYSICAL CHARACTERS.

I. CLEAVAGE.

Cubic. — METALLIC LUSTER: Galena.

NONMETALLIC LUSTER: Halite: Sylvite. The cleavage of Anhydrite (also of Cyrolite) simulates this. Cf. also Corundum, p. 413.

Octahedral. — Fluorite; Diamond. Magnetite (also Franklinite) has often distinct octahedral *parting*.

Dodecahedral. — Sphalerite. Also, imperfect, Sodalite; Hauynite.

Rhombohedral. — Calcite and other species of the same group (pp. 437–445) angles 75° and 105°.

Square Prismatic (90°). — Scapolite; Rutile; Xenotime.

Prismatic. — Barite (78°½, 101°½); Celestite; Amphibole (54° and 126°), etc.

Basal. — Metallic Luster: Graphite; Molybdenite.

Nonmetallic Luster: Apophyllite; Topaz; Talc; the Micas and Chlorites; Chalcophyllite, etc. Pyroxene often shows marked basal *parting*.

Pinacoidal. — Metallic Luster: Stibnite.

Nonmetallic Luster: Gypsum; Orpiment; Euclase; Diaspore; Sillimanite; Cyanite; Feldspars.

II. HARDNESS.

1. **Soft Minerals.** — The following minerals are conspicuously *Soft*, that is, H = 2 or less; they hence have a *greasy* feel. (See further the Tables, pp. 679 to 688.)

Metallic Luster: Graphite; Molybdenite; Tetradymite; Sternbergite; Argentite; Nagyagite; some of the Native Metals (Lead, etc.).

Nonmetallic Luster: Talc; Pyrophyllite; Brucite; Tyrolite; Orpiment; Cerargyrite; Cinnabar; Sulphur; Gypsum.

Also Calomel, Arsenolite, and many hydrous sulphates, phosphats, etc.

2. **Hard Minerals.** — Minerals whose hardness is equal to or greater than 7 (Quartz = 7). The following minerals are here included:

Luster Nonmetallic

Quartz (p. 403)	7	Hambergite (p. 620)	7·5
Tridymite (p. 407)	7	Zircon (p. 520)	7·5
Barylite (p. 498)	7	Andalusite (p. 524)	7·5
Dumortierite (p. 543)	7	Beryl (p. 495)	7·5–8
Danburite (p. 522)	7–7·25	Lawsonite (p. 540)	7·5–8
Boracite (p. 620)	7	Phenacite (p. 514)	7·5–8
Zunyite (p. 505)	7	Gahnite (p. 420)	7·5–8
Cyanite (p. 526)	5–7·25	Hercynite (p. 420)	7·5–8
Tourmaline (p. 540)	7–7·5	Spinel (p. 419)	8
Garnet (p. 505)	6·5–7·5	Topaz (p. 523)	8
Iolite (p. 497)	7–7·5	Rhodizite (p. 621)	8
Staurolite (p. 543)	7–7·5	Chrysoberyl (p. 423)	8·5
Schorlomite (p. 510)	7–7·5	Corundum (p. 413)	9
Sapphirine (p. 544)	7·5	Diamond (p. 345)	10
Euclase (p. 529)	7·5		

The following minerals have hardness equal to 6 to 7, or 6·5 — 7.

Luster Metallic: Iridosmine (p. 355); Iridium (p. 355); Sperrylite (p. 379).

Luster Nonmetallic: Ardennite (p. 539); Axinite (p. 534); Bertrandite (p. 539); Cassiterite (p. 425); Chrysolite (p. 511); Diaspore (p. 431); Elpidite (p. 496); Epidote (p. 531); Forsterite (p. 513); Gadolinite (p. 529); Jadeite (p. 479); Partschinite (p. 510); Sillimanite (p. 526); Spodumene (p. 480); Trimerite (p. 515).

III. SPECIFIC GRAVITY.

Attention is called to the remarks in Art. **302** (p. 199), on the relation of specific gravity to chemical composition. Also to the statements in Art. **303** as to the *average* specific gravity among minerals of metallic and nonmetallic luster respectively. The species in each of the separate lists of Table II of minerals classified with reference to crystallization are arranged according to ascending *specific gravities*. Hence the lists give at a glance minerals distinguished by both low and high density.

IV. LUSTER. (See Art. 364, p. 249)

Metallic. — Native metals; most Sulphides; some Oxides, those containing iron, manganese, lead, etc.

Submetallic. — Here belong chiefly certain iron and manganese compounds, as Ilmenite; Ilvaite; Columbite; Tantalite (and allied species); Wolframite; Braunite; Hausmannite. Also Brookite; Uraninite, etc.

Adamantine. — Here belong minerals of high refractive index: (*a*) Some *hard* minerals: Diamond; Corundum; Cassiterite; Zircon; Rutile. (*b*) Many species of *high density*, as compounds of lead, also of silver, copper, mercury. Thus, Cerussite, Anglesite, Phosgenite, etc.; Cerargyrite; Cuprite; some Cinnabar, etc. (*c*) Also certain varieties of Sphalerite, Titanite and Octahedrite.

Metallic-Adamantine. — Pyrargyrite; some varieties of the following: Cuprite, Cerussite, Octahedrite, Rutile, Brookite.

Resinous or Waxy. — Sphalerite; Sulphur; Elæolite; Serpentine; many Phosphates.

Vitreous. — Quartz and many Silicates, as Garnet, Beryl, etc.

Pearly. — The foliated species: Talc, Brucite, Pyrophyllite. Also (on cleavage surfaces) conspicuously the following: Apophyllite, Stilbite, Heulandite. Also, less prominent: Barite; Celestite; Diaspore; some Feldspar, and others.

Silky. — Some fibrous minerals, as Gypsum, Calcite; also Asbestus; Malachite.

V. COLOR.

The following lists may be of some use in the way of suggestion. It is to be noted, however, that especially in the case of metallic minerals a slight surface change may alter the effect of color. Further, among minerals of nonmetallic luster particularly, no sharp line can be drawn between colors slightly different, and many variations of shade occur in the case of a single species. For these reasons no lists, unless inconveniently extended, could make any claim to completeness.

(*a*) Metallic Luster.

Silver-white, Tin-white. — Native silver; Native Antimony, Arsenic and Tellurium; Amalgam; Arsenopyrite and Löllingite; several sulphides, arsenides, etc., of cobalt or nickel, as Cobaltite (reddish); some Tellurides; (Bismuth (reddish).) No sharp line can be drawn between these and the following group.

Steel-gray. — Platinum; Manganite; Chalcocite; Sylvanite; Bournonite.

Blue-gray. — Molybdenite; Galena.

Lead-gray. — Many sulphides, as Galena (bluish); Stibnite; many Sulpharsenites, etc., as Jamesonite, Dufrenoysite, etc.

Iron-black. — Graphite; Tetrahedrite; Polybasite; Stephanite; Enargite; Pyrolusite; Magnetite; Hematite; Franklinite.

Black (with submetallic luster). — Ilmenite; Limonite; Columbite; Tantalite, etc.; Wolframite; Ilvaite; Uraninite, etc. The following are usually brownish black: Braunite; Hausmannite.

Copper-red. — Native copper.

Bronze-red. — Bornite (quickly tarnished giving purplish tints); Niccolite.

Bronze-yellow. — Pyrrhotite; Pentlandite; Breithauptite.

Brass-yellow. — Chalcopyrite; Millerite (bronze). Pale brass-yellow: Pyrite; Marcasite (whiter than Pyrite).

Gold-yellow. — Native gold; chalcopyrite and pyrite sometimes are mistaken for gold.

Streak. — The following minerals of metallic luster are notable for the color of their *streak:*

Cochineal-red: Pyrargyrite.

Cherry-red: Miargyrite.

Dull Red: Hematite; Cuprite; some cinnabar.

Scarlet: Cinnabar (usually nonmetallic).

Dark Brown: Manganite; Franklinite; Chromite.

Yellow: Limonite.

Tarnish. — The following are conspicuous for their bright or variegated tarnish: Chalcopyrite; Bornite (purplish tints); Tetrahedrite; some Limonite.

(*b*) Nonmetallic Luster.

Colorless. — In Crystals: Quartz; Calcite; Aragonite; Gypsum; Cerussite; Anglesite; Albite; Barite; Adularia; Topaz; Apophyllite; Natrolite and other Zeolites; Celestite; Diaspore; Nephelite; Meionite; Calamine; Cryolite; Phenacite, etc.

Massive: Quartz; Calcite; Gypsum; Hyalite (botryoidal).

White. — Crystals: Amphibole (tremolite); Pyroxene (diopside, usually greenish).

Massive: Calcite; Milky Quartz; Feldspars, especially Albite; Barite; Cerussite, Scapolite; Talc; Meerschaum; Magnesite; Kaolinite; Amblygonite, etc.

Blue. — Blackish Blue: Azurite; Crocidolite.

Indigo-blue: Indicolite (Tourmaline); Vivianite.

Azure-blue: Lazulite; Azurite; Lapis Lazuli; Turquois.

Prussian-blue: Sapphire; Cyanite; Iolite; Azurite; Chalcanthite and many copper compounds.

SKY-BLUE, MOUNTAIN-BLUE: Beryl; Celestite.

VIOLET-BLUE: Amethyst; Fluorite.

GREENISH BLUE: Amazon-stone; Chrysocolla; Calamine; Smithsonite; some Turquois; Beryl.

Green. — BLACKISH GREEN: Epidote; Serpentine; Pyroxene; Amphibole.

EMERALD-GREEN: Beryl (Emerald); Malachite; Dioptase; Atacamite; and many other copper compounds; Spodumene (hiddenite); Pyroxene (rare); Gahnite; Jadeite and Jade.

BLUISH GREEN: Beryl; Apatite; Fluorite; Amazon-stone; Prehnite; Calamine; Smithsonite; Chrysocolla; Chlorite; some Turquois.

MOUNTAIN GREEN: Beryl (aquamarine); Euclase.

APPLE-GREEN: Talc; Garnet; Chrysoprase; Willemite; Garnierite; Pyrophyllite: some Muscovite; Jadeite and Jade, Pyrophyllite.

PISTACHIO-GREEN: Epidote.

GRASS-GREEN: Pyromorphite; Wavellite; Variscite; Chrysoberyl.

GRAYISH GREEN: Amphibole and Pyroxene, many common kinds; Jasper; Jade.

YELLOW-GREEN to OLIVE-GREEN: Beryl; Apatite; Chrysoberyl; Chrysolite (olive-green); Chlorite; Serpentine; Titanite Datolite; Olivenite; Vesuvianite.

Yellow. — SULPHUR-YELLOW: Sulphur; some Vesuvianite.

ORANGE-YELLOW: Orpiment; Wulfenite; Mimetite.

STRAW-YELLOW, also WINE-YELLOW, WAX-YELLOW: Topaz; Sulphur; Fluorite; Cancrinite; Wulfenite; Vanadinite; Willemite; Calcite; Barite; Chrysolite; Chondrodite; Titanite; Datolite, etc.

BROWNISH YELLOW: Much Sphalerite; Siderite; Göthite.

OCHER-YELLOW: Göthite: Yellow ocher (limonite).

Red. — RUBY-RED: Ruby (corundum); Ruby spinel; much Garnet; Proustite; Vanadinite; Sphalerite; Chondrodite.

COCHINEAL-RED: Cuprite; Cinnabar.

HYACINTH-RED. — Zircon; Crocoite.

ORANGE-RED. — Zincite; Realgar; Wulfenite.

CRIMSON-RED: Tourmaline (rubellite); Spinel, Fluorite.

SCARLET-RED: Cinnabar.

BRICK-RED: Some Hematite (red ocher).

ROSE-RED to PINK: Rose quartz; Rhodonite; Rhodochrosite; Erythrite; some Scapolite. Apophyllite and Zoisite; Eudialyte; Petalite; Margarite.

PEACH-BLOSSOM RED to LILAC: Lepidolite; Rubellite.

FLESH-RED: Some Orthoclase; Willemite (the variety troostite); some Chabazite; Stilbite and Heulandite; Apatite; rarely Calcite; Polyhalite..

BROWNISH RED: Jasper; Limonite; Garnet; Sphalerite; Siderite; Rutile.

Brown. — REDDISH BROWN: Some Garnet; some Sphalerite; S aurolite; Cassiterite; Rutile.

CLOVE-BROWN: Axinite; Zircon; Pyromorphite.

YELLOWISH BROWN: Siderite and related carbonates; Sphalerite; Jasper; Limonite; Göthite; Tourmaline; Vesuvianite; Chrondrodite; Staurolite.

BLACKISH BROWN: Titanite; some Siderite; Sphalerite.

SMOKY BROWN: Quartz.

Black: Tourmaline; black Garnet (melanite); some Mica (especially biotite); also some Amphibole, Pyroxene and Epidote (these are mos'ly greenish or brownish black); further, some Sphalerite and some kinds of Quartz (varying from smoky brown to black); also Allanite; Samarskite. Some black minerals with submetallic luster are mentioned on p. 692.

Streak. — The *streak* is to be noted in the case of some minerals with nonmetallic luster. By far the majority have, even when deeply colored in the mass (e.g. Tourmaline), a streak differing but little from white. The following may be mentioned:

ORANGE-YELLOW: Zincite, Crocoite.

COCHINEAL-RED: Pyrargyrite and Proustite.

SCARLET RED: Cinnabar.

BROWNISH RED: Cuprite; Hematite.

BROWN: Limonite.

The streak of the various copper, green and blue minerals, as Malachite, Azurite, etc., is about the same as the color of the mineral itself, though often a little paler.

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